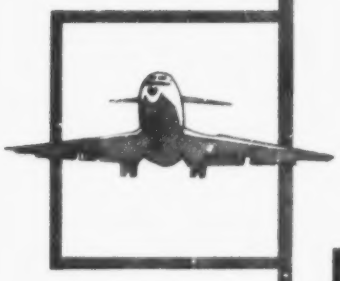
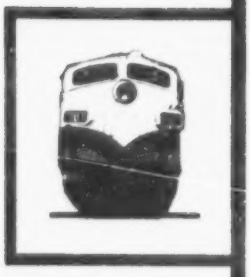
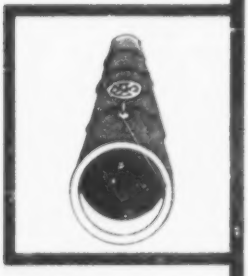
FEB 8 1982

982.1-23 TD1.120:AAS-81-2

COMPLETED
60







NATIONAL TRANSPORTATION SAFETY BOARD

ORIGINAL

WASHINGTON, D.C. 20594

SPECIAL STUDY

CABIN SAFETY IN LARGE TRANSPORT AIRCRAFT

NTSB-AAS-81-2

UNITED STATES GOVERNMENT

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. NTSB-AAS-81-2	2. Government Accession No. PB82-129297	3. Recipient's Catalog No.
4. Title and Subtitle Special Study—Cabin Safety In Large Transport Aircraft		5. Report Date September 9, 1981
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address National Transportation Safety Board Bureau of Technology Washington, D.C. 20594		10. Work Unit No. 3180A
		11. Contract or Grant No.
		13. Type of Report and Period Covered Special Study
12. Sponsoring Agency Name and Address NATIONAL TRANSPORTATION SAFETY BOARD Washington, D. C. 20594		14. Sponsoring Agency Code

15. Supplementary Notes
The subject report was distributed to NTSB mailing lists: 1A, 8A and 8B.

16. Abstract

A study by the National Transportation Safety Board showed that in 58.4 percent of the 77 survivable/partially survivable passenger carrying transport aircraft accidents/incidents occurring since 1970, there were failures of cabin furnishings. These failures killed, injured, entrapped or otherwise incapacitated aircraft occupants preventing successful emergency escape in many cases. Failures of cabin furnishings also created obstacles to egress by blocking aisles and exits.

Regulations dealing with occupant protection in crashes were last updated 30 years ago. They do not adequately reflect actual crash experience nor do they provide adequate protection to occupants in survivable crashes, especially the more severe crashes, where it is most needed.

Recent accident experience supports the need to upgrade the current minimum design standards. Moreover, the technology exists for upgrading existing design and testing methods for cabin furnishings to meet the upgraded regulations.

17. Key Words	18. Distribution Statement
Transport aircraft accidents; crashworthiness; seats/restraints; cabin furnishings; cabin safety; seat failures; static testing; dynamic testing.	This document is available to the public through the National Technical Information Service-Springfield, Virginia 22161 *(Always refer to number listed-in item 2)*

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	53	

NTSB Form 1765.2 (Rev. 9/74)

BEST DOCUMENT AVAILABLE

CONTENTS

INTRODUCTION 1

ACCIDENT DATA 3
Location/Phase of Operation 3
Cases in Which Failures Occurred 4
Cabin Furnishings 7

CASE HISTORIES 10

DISCUSSION 21
Regulations and Standards. 21
Design Technology 25
Testing Technology. 27
Crashworthiness Work 29

CONCLUSIONS 31

RECOMMENDATIONS 32

APPENDIXES 35
Appendix A—Definition of Phase of Operation 35
Appendix B—Transport Category Aircraft Seat Strength Proposed Modification to FAR Part 25 36
Appendix Table 1—Accidents/Incidents Meeting Criteria 51
Appendix Table 2—Accidents/Incidents With Failures 53

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D. C. 20594

SPECIAL STUDY

Adopted: September 9, 1981

CABIN SAFETY IN LARGE TRANSPORT AIRCRAFT

INTRODUCTION

On September 23, 1962, a Lockheed Constellation ditched in the North Atlantic with 76 persons on board. Most of the survivors believed that the deceleration of the aircraft was not extreme. However, many seat units failed at impact, creating egress difficulties for passengers who first had to free themselves from the pile of seats. The Bureau of Aviation Safety of the Civil Aeronautics Board (CAB) (the predecessor agency of the National Transportation Safety Board) concluded that these seat failures probably prevented at least some of the 28 persons who did not survive the accident from evacuating the aircraft. As a result, the CAB recommended to the Federal Aviation Agency (the predecessor agency of the Federal Aviation Administration) (FAA):

> . . . We are convinced from this accident and others in recent years that an increase in the minimum level (of crashworthiness) is long overdue. Accordingly, it is recommended that the studies relative to crash load factors and dynamic seat testing criteria which we understand are now under way in your agency be expedited toward the end of achieving improved safety in this area at the earliest date.

In response to this recommendation, the FAA stated:

> We concur with the views contained in (your) recommendation relative to adequacy of seat tie-down. We wish to assure you that the need for necessary studies relative to crash load factors and dynamic seat testing criteria is clearly recognized and that these studies are being expedited by our Aircraft Development Service consistent with available manpower and funds.

In 1962, the regulations regarding crash forces were already about 10 years old; today, 30 years after the standard was established and almost 20 years after the first recommendation, these regulations have yet to be changed, and seats and other cabin furnishings continue to fail in aircraft accidents regardless of the severity of impact.

Since 1970, almost 60 percent of the large transport aircraft involved in survivable and partially survivable major accidents and incidents investigated by the Safety Board have exhibited failures of cabin furnishings. Of the more than 4,800 passengers and crew involved in these accidents, over 1,850 were injured or killed. The Safety Board believes that many of these injuries and deaths would have been prevented had cabin furnishings not failed, particularly in accidents involving fire (about 46 percent).

The Safety Board conducted this special study to determine whether the failure of cabin furnishings is an ongoing problem and whether regulations dealing with these areas are adequate.

The Safety Board set certain criteria for choosing the cases used in this study. Specific detailed information about failures of cabin furnishings was found most consistently in reports by the Safety Board of major investigations and by its field investigations in which Washington headquarters technical specialists had participated. For the period 1970 through 1980, this included about 234 accidents and incidents.

To reflect realistically today's air carrier fleet, the study was limited to turbojet and turboprop powered aircraft capable of carrying 30 or more passengers, and type-certificated under Civil Air Regulations (CAR) Part 4b -- Airplane Airworthiness Transport Categories, or Federal Aviation Regulations (FAR) Part 25 -- Airworthiness Standards: Transport Category Airplanes. Of the 234 cases, 108, or 46 percent, met these criteria. Since the study deals with cabin safety, accidents and incidents involving nonpassenger carrying flights such as cargo, ferry, and crew training flights were eliminated, reducing the study group to 88 cases.

The study was limited further to those accidents in which the crashes were survivable or partially survivable. 1/ The definition of a survivable accident as used by the Safety Board was developed from crash injury research done by Aviation Crash Injury Research (AvCIR) of Cornell University and Aviation Safety Engineering and Research (AvSER) of the Flight Safety Foundation. The definition was used in the Aircraft Crash Survival Design Guide 2/ which was prepared for the U.S. Army Research and Technology Laboratories, in conjunction with other Government agencies. The definition follows:

> Survivable Accident: An accident in which the forces transmitted to the occupant through his seat and restraint system do not exceed the limits of human tolerance to abrupt accelerations and in which the structure in the occupant's immediate environment remains substantially intact to the extent that a livable volume is provided for the occupants throughout the crash sequence.

Although this definition is subjective and open to some degree of interpretation, the Safety Board has found it can be used by trained investigators to assess survivability accurately.

Although the precise g-levels beyond which human tolerance is exceeded is not universally agreed upon, in the late 1960's, the Safety Board, FAA-CAMI, and others in and out of Government concluded, based on studies, experiments, and accident investigation into injury causation done over two decades, that. under certain conditions, the human body can withstand forces two to three times greater than those cited in 14 CFR 25.561 (9.0g forward, 4.5g downward, 1.5g sideward, and 2.0g upward), without irreversible injury. The conditions are--that the occupant is restrained by lap belt and that the aircraft and occupants experience a rate of onset and duration of forces typical of those experienced in survivable crashes. These force parameters were determined through investigation, research, and experimentation which culminated in the full scale crash tests of aircraft. The ranges of these forces are: 3/

1/ The term survivable, without further qualification, will be used hereafter to encompass both categories of accidents.

2/ Aircraft Crash Survival Design Guide, USARTL-TR-79-22, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, 1980.

3/ For comparison, in the forward direction, the Air Force design recommendation is 45g for 0.1 second, based on seatbelt and upper torso restraint. Findings from human free-falls and corroborating findings from animal tests indicate that tolerance in the forward direction may be as high as 237g (for 0.35 seconds at 11,250g/sec) with optimum full-body restraint.

BEST DOCUMENT AVAILABLE

Direction	g's
Forward	20-25
Downward	15-20
Sideward	10-15
Upward	20
Duration from 0.1 to 0.2 seconds	
Rate of onset 50g/second	

Many of these tests have also shown that the limits in the forward direction can be doubled by the use of an upper torso restraint (shoulder harness). 4/

Investigations have shown, however, that even when crash forces fall within the survivable range, few if any survive the accident because of postcrash fire or emergency evacuation problems. Crashes have been found to be nonsurvivable for certain occupants when the forces transmitted to occupants were within human tolerance to abrupt acceleration, but the seat/restraint system failed, allowing the occupant to become a missle traveling at essentially the same velocity as the aircraft just before impact. The occupant, free to strike other objects in the aircraft, died or was incapacitated, and thereby could not effect a successful emergency evacuation. Crashes were also found to be "partially survivable" when the aircraft itself struck an object that destroyed the integrity of the hull or caused forces to be transmitted to the occupant which surpassed the human tolerance limits in a localized area. While the crash forces in this portion of the aircraft were nonsurvivable, those in other areas of the aircraft were within the survival envelope.

After applying the definition above and taking into account the limitations of the definition, 11 of the 88 cases were found to be nonsurvivable, leaving 77 for further study.

ACCIDENT DATA

Location/Phase of Operation

Data developed from evaluation of 77 survivable cases showed that airport proximity and crash survivability are related. (See table 1 and appendix table 1.) About 58 percent of the survivable accidents and incidents occurred on the airport, while about 26 percent occurred more than 5 miles away. Almost 55 percent of nonsurvivable accidents occurred more than 5 miles from the airport and only about 36 percent occurred on the airport. Those survivable/partially survivable accidents occurring on the airport made up the largest single group in this study.

Table 1.--Transport Aircraft Accidents by Airport Proximity.

	On	1-5 miles	Greater than 5 miles	Total
Survivable/Partially-Survivable	45	12	20	77
Percent	58.44	15.58	25.97	
Nonsurvivable	4	1	6	11
Percent	36.36	9.09	54.55	

4/ A compilation of data on human tolerance to abrupt acceleration can be found in Snyder, R.G., Advanced Techniques in Crash Impact Protection and Emergency Egress from Air Transport Aircraft, AGARD-AG-221, June 1976.

BEST DOCUMENT AVAILABLE

The majority of these accidents/incidents occurred during the takeoff, approach, and landing phases of operation. (See appendix A for definitions of phases of operation.) About 75 percent of these survivable cases fall into those three categories.

The accident types cited most often include collision with ground/water, engine failure or malfunction, and collision with obstacle. (See table 2.) These accident types comprise about 38 percent of the survivable cases. The landing-type accidents which include gear retracted, hard landing, overshoot and undershoot, were cited in about 22 percent of these cases. In-flight accident types such as turbulence, evasive maneuver, and uncontrolled altitude deviation accounted for 14 percent.

Cases in Which Failures Occurred

In 45, or 58.4 percent, of the 77 survivable cases, there was evidence of failures of seat/restraint systems or other furnishings in the aircraft cabin. These 45 cases include accidents/incidents in flight as well as those on the ground. (See appendix table 2 for more detailed information.)

Table 2.--Transport Aircraft Accidents by Phase of Operation.

Accident Type	Static	Taxi	Takeoff	Climb	Cruise	Descent	Approach	Landing	Total
Ground-water loop-swerve		1							1
Gear retracted								1	1
Hard landing								3	3
Overshoot								7	7
Undershoot							2	4	6
Collision with aircraft		2	1			1	2	1	7
Collision with ground/water			2				7	1	10
Collision with obstacle			5				4		9
Stall/mush			1	1			1		3
Fire or explosion in-flight			1						1
Airframe failure			3	3	1				7
Engine failure or malfunction			5		2		1	2	10
Prop/rotor failure							1		1
Turbulence				1	3		1		5
Evasive maneuver			1		2	1	1		5
Uncontrolled altitude deviation					1				1
Miscellaneous	1					1			2
Totals	1	3	19	5	9	3	20	19	79 1/

1/ Total includes two cases involving a collision between two transport aircraft.

In 29, or 64.4 percent, of these cases, the accident/incident occurred on the airport. Consistent with the larger samples, about 82 percent of the 45 accidents/incidents occurred during the takeoff, approach, and landing phases of operation. (See table 3.)

Table 3.--Transport Aircraft Accidents by Airport Proximity and Phase of Operation.

Phase of Operation	On	1-5 miles	Greater than 5 miles	Total
Taxi	2			2
Takeoff	10	1		11
Climb			2	2
Cruise			4	4
Descent			1	1
Approach	4	5	2	11
Landing	14		1	15
Total	30 1/	6	10	46 1/

1/ Includes one case involving a collision between two transport aircraft.

In 10 of the 29 accidents which occurred on airports, no obstacles were struck. In most of the remaining 19 cases, more than 1 type of obstacle was usually involved in a given accident. As shown in the tabulation below, the most commonly involved obstacles were lights and their supporting stanchions, fences, dikes and embankments, and ditches.

Obstacle	No. of times involved
Lights/stanchions	10
Fences	6
Hills/mounds	2
Navigation facilities	2
Embankment/dike	7
Ditch	6
Roadways/concrete walkways or foundations	1
Boulders/rocks	3
Trees/stumps	4
Aircraft	2
Buildings	1
Autos	2

Providing a typical description of a group of accidents is difficult because of the complexities and interactions of the individual events of each. However, these 29 accidents suggest that the following major events typically occur during on-airport accidents. The average aircraft speeds are about 130 knots or below since most accidents occur during the takeoff or landing phases. The first event is the collapse or tearaway of one or more landing gears caused either by striking objects or by hard landings. Usually, the fuselage structure is damaged, mainly by crushing and tearing of the underside of the fuselage often accompanied by localized displacement or breaks in the cabin floor structure.

Usually the wings are damaged; much of this damage is minor, consisting of some crushing and abrading of the leading and trailing edges and tearing or puncturing of the skin. Occasionally, wing-mounted engines are torn away, and in some cases, major portions of the wing structure are separated from the fuselage. Whenever the wing structure is opened and fuel escapes, the potential for fire exists. Fire erupted in 21, or 46.7 percent, of the 45 accidents in which cabin furnishings failed. Fires erupted in 56.7 percent of the 29 accidents that occurred on the airport. (See appendix table 2.)

Finally, in just over half of the on-airport accidents, circumferential breaks or buckles will occur in the fuselage, almost always just aft of the cockpit or just forward of the empennage. These areas are the most vulnerable portions of the structure to bending and torsional loading during crashes.

Many factors, such as aircraft velocity and attitude at impact, affect the loads on an aircraft and ultimately its passengers. Different types of terrain, such as a paved surface, hard-packed earth, mud, sand, or dense vegetation, will make a difference in the rate at which the aircraft's velocity is reduced. Large changes in velocity over extremely short periods of time can result from the movement of the aircraft through terrain types which differ greatly. These abrupt accelerations also occur when various obstacles are struck, resulting in forces which may be spread throughout the structure or focused in highly localized areas of the aircraft. These forces can and do act in all directions and probably will never act in one direction only. The exact forces being transmitted through the aircraft structure to the aircraft cabin and its occupants during a crash are continually changing and are essentially impossible to predict accurately for all cases. Many times, the forces, and therefore the severity of these accidents, are increased needlessly by collisions with various obstacles in the airport environment.

Since it is impossible to completely control the crash environment in off-airport accidents, it becomes even more important to design the aircraft and its components so that the occupants are adequately protected in survivable crashes. The following tabulation was compiled from data contained in Appendix Table 2. It shows the types of obstacles encountered by aircraft in survivable off-airport accidents/incidents where failures occurred. Six of the 16 cases occurred in flight and no obstacles were involved. Three additional accidents involved collisions with water where no other objects were struck. The seven remaining off-airport cases typically involved collisions with more than one of the following obstacles.

Obstacle	No. of times involved
Trees/Poles	8
House/Building	5
Power Lines	1
Autos	1
Crops	1

Trees/poles are most often involved in the off-airport accidents. Impacts with these objects tend to cause crash forces to be focused in highly localized areas and to destroy large portions of the fuselage skin. This destruction allows much of the crash energy to be absorbed, but results in accidents which are only partially survivable. In these cases, it is critical that occupants be retained in their seats and that the seats remain attached to the floor structure throughout the crash sequence, i.e., the integrity of the tiedown chain (seat, restraints, seat attachments, and floor) must be maintained.

Cabin Furnishings

Seat/Restraint System.--Components of the seat/restraint systems failed in 84.4 percent of the accidents/incidents examined. (See appendix table 2.) Most of the failures typically occurred in the seat legs and seat-to-track attach points. In many cases, the cabin floor was deformed by localized impacts or bending and buckling of the fuselage, causing seat tracks to break and separate and allowing the partially unrestrained seat to rotate laterally. The uncontrolled movement of the seat placed additional stresses on the remaining seat attach points, seat legs, or floor tracks, resulting in additional failures. (See figures 1 and 2.) Additionally, seat backs, seat pans, frames, arm rests, and tray tables failed. Some component of the restraint system failed in about 22 percent of the cases. Most of these were failures of the belt attachment hardware rather than failures of the belt webbing material.

Overhead Furnishings.--Overhead panels, racks, and passenger-service units failed in 77.8 percent of the cases examined. (See appendix table 2.) Failures of overhead furnishings were placed into two categories--failures that caused injury and those that hampered emergency egress.

Head injuries most often resulted from failures of overhead furnishings. While these injuries may not be serious, a person could lose consciousness temporarily or could be stunned, resulting in confusion and inability to identify and react to an emergency situation. As a result, valuable evacuation time may be lost, especially when fire or the potential for fire is present.

In the cases examined, the basic designs or failures of overhead racks or bins allowed items stored there to become missiles during the crash sequence; these items inflict injuries, in some cases incapacitating ones. Emergency evacuation was also hampered when items stored in overhead compartments were released. Even items, such as blankets, pillows, and coats, which are unlikely to cause injury when they become loose, were thrown into the aisles and against bulkheads adjacent to the exits, creating barriers to exits.

Failed overhead racks or bins also blocked movement in the cabin by cutting off access to and from aisles and overwing exits. (See figure 3.) Figure 4 shows hazards created by failed passenger service units.

Galley Equipment.--Components of galley equipment failed in about 62 percent of the accidents/incidents examined. In almost all cases, food, eating utensils, and waste material were thrown from open storage areas or from containers and drawers that did not remain latched. Often, the drawers and their inserts were released. Since the galleys were usually located near exits, the materials released from them blocked egress. Failures of individual galley components or displacement of entire galley units have blocked exit doors so that they could only be opened partially or not at all.

Flight attendants, whose main duty is to provide direction and assistance to passengers in emergencies, were seated at their designated positions at the exits where the galleys were located. In several instances, hot liquids from containers splashed onto the flight attendants. Although these injuries were minor, the potential for serious injury was present. The potential is also great for injury to flight attendants when galley drawers come open and the flight attendants, whether restrained or not, come into contact with the sharp edges of these opened drawers or with objects released from them. Although these injuries may be minor, they can seriously compromise the flight attendants' ability to assist passengers during emergencies.

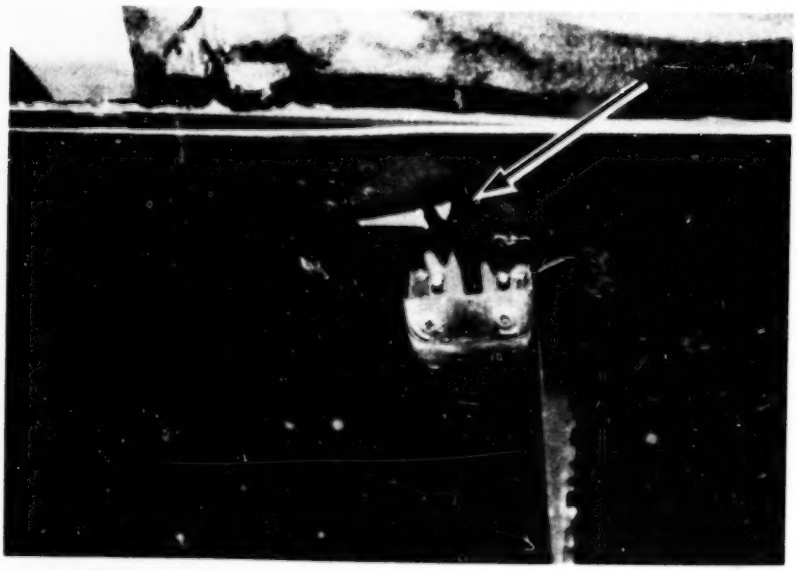


Figure 1.--Failure at seat frame to seat leg attach point during overrun accident.

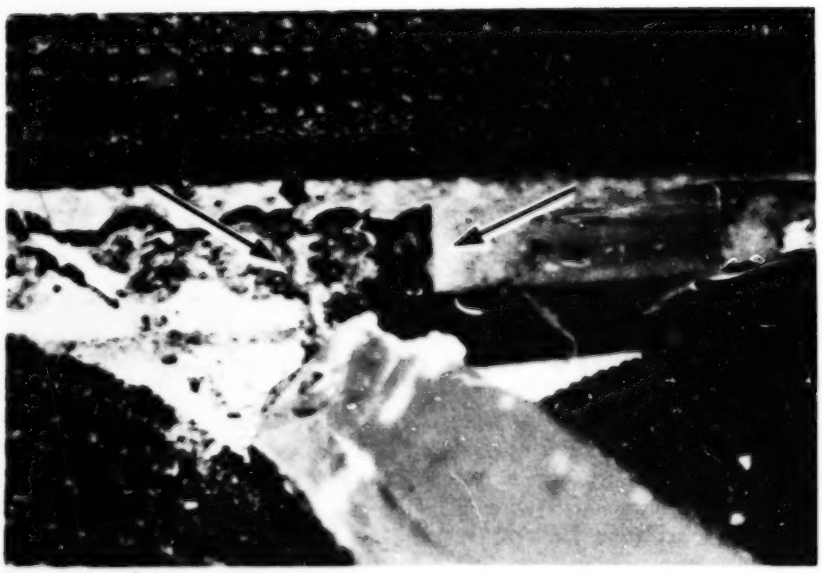


Figure 2.--Failure of floor track at attach point with separation of leg from horizontal bar during overrun accident.

BEST DOCUMENT AVAILABLE

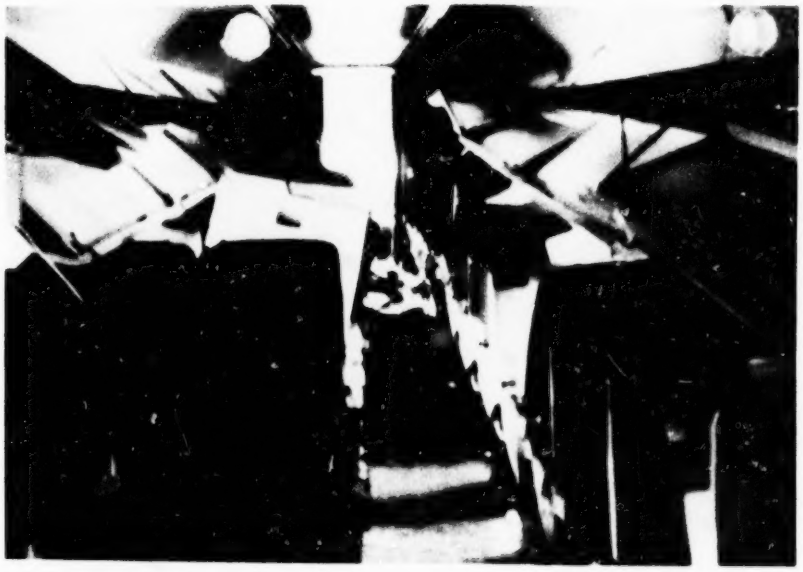


Figure 3.--Typical collapsed overhead racks.

Figure 4.--View toward the forward portion of the aircraft.
(Note the passenger service units
hanging over the A and E seats in each row.)

BEST DOCUMENT AVAILABLE

CASE HISTORIES

Case 1

On June 23, 1976, Allegheny Airlines Flight 121, a DC-9, N994VJ, crashed while attempting a go-around during an approach to runway 27R at Philadelphia International Airport. 5/ The aircraft contacted the ground at a point about 6,000 feet down and slightly to the right of the runway. After sliding about 2,000 feet, it came to rest on the grass-covered infield, perpendicular to the runway. The terrain was level and there were no obstacles. The tail of the aircraft, with engines mounted, separated from the fuselage and was found about 400 feet back along the crash path. There was no postcrash fire. (See figure 5.)

The bottom of the fuselage was damaged severely. The skin was torn and abraded, frames were crushed, stringers were damaged along the entire length of the fuselage, and the floor above the landing gears was buckled upward. The wings remained intact and connected to the fuselage; there were no fuel leaks from the wing tanks. (See figure 6.)

Inside the cabin, galley equipment, magazine racks, overhead racks, and light panels failed, and baggage and garments were thrown into the aisle. The cabin floor was buckled and displaced upward as much as 12 inches in some sections. About 95 seats, including 3 crew seats, failed at impact. The passenger seats had been rated to withstand 7.5g in the downward direction and 4.5g in the upward direction; the required minimums are 4.5g downward and 2.0g upward. The crew seats had been tested to 8.63g downward. At the Safety Board's request, the Douglas Aircraft Company performed a failure mode analysis on the failed flight attendant seat and found that forces experienced in the forward fuselage as a result of impact were at least 10g in the downward direction.

No one among the 107 persons on board the aircraft was killed; however, 36 persons were injured seriously, the majority of which suffered spinal fractures. Other injuries included fractures to extremeties, back sprains and strains, whiplash, contusions, lacerations and abrasions to the head, face, and extremities, and broken teeth. Only 20 passengers reported no injuries.

Passenger and crew statements included the following observations. The seat failures occurred at impact and caused passengers to be thrown into adjacent seats, or pinned them between seats, between the floor and seats, and between seats and side walls. Failed seats were thrown into the aisle and against other seats, hampering the flow of passengers to the exits. As many as 12 passengers were immobilized by injuries or trapped by failed seats and were still in the aircraft when firemen arrived. In addition, overhead storage racks spilled their contents into the aisles. Some passengers encountered baggage and garments in the aisle during evacuation, and some stopped to retrieve possessions before leaving the aircraft. One flight attendant, whose seat failed incapacitating her with a spinal fracture, recalled seeing two coffee pots and liquid on the floor. (See figures 7 and 8.)

With regard to survivability in this accident, the Safety Board has drawn the following conclusions:

- The g-levels were well in excess of those cited in the regulations, yet the accident clearly was survivable. Force levels were within the range of human tolerance since there were no fatalities.

5/ Aircraft Accident Report: Allegheny Airlines, Inc., Douglas DC-9, N994VJ, Philadelphia, Pennsylvania, June 23, 1976, (NTSB-AAR-78-2).

Figure 5.--View of crash site.
(Note aircraft tail and engines in foreground and to far left.)

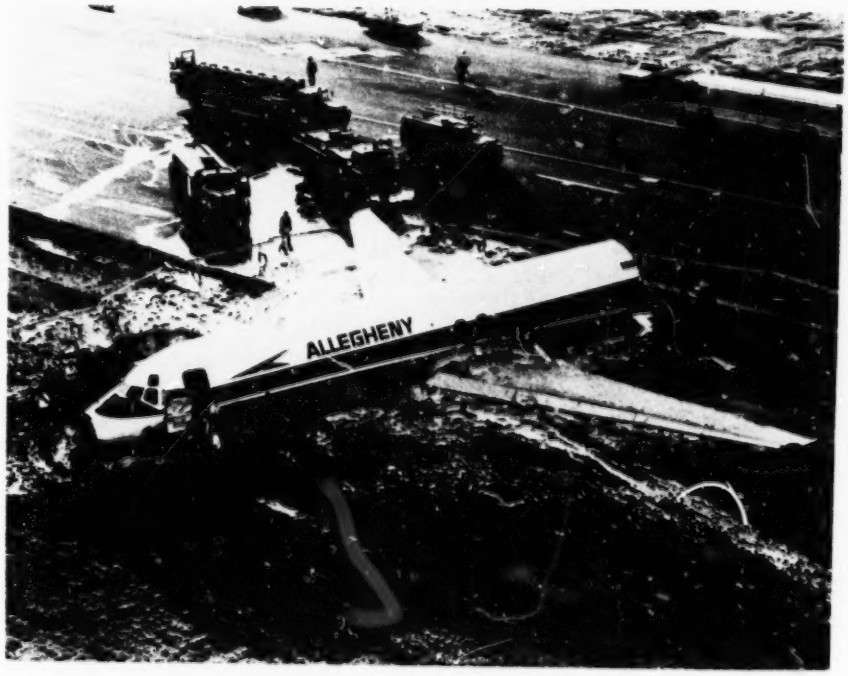


Figure 6.--View of fuselage exterior.

BEST_DOCUMENT_AVAILABLE

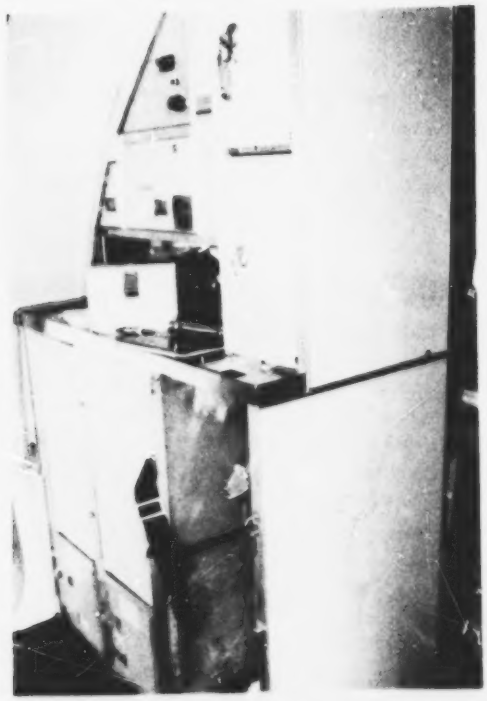


Figure 7.--No. 2 galley.
(Note flight attendant's keys and failed trash trolley restraint strap fastener.)

Figure 8.--View of passenger seats forward from row 20.

BEST DOCUMENT AVAILABLE

- o Injuries were caused by failed seat systems and other cabin furnishings.
- o Had the seat systems and cabin furnishings been designed and built to withstand the higher loads, few if any injuries would have occurred.
- o Had fire erupted, at least 12 persons would have died because of incapacitation, entrapment, or hampered egress, caused by preventable failures of cabin furnishings.

Case 2

On November 12, 1975, an Overseas National Airways DC-10, N1032F, was attempting to take off from runway 13R at John F. Kennedy International Airport, Jamaica, New York. 6/ During the takeoff roll, several sea gulls were ingested into the No. 3 engine and the takeoff was rejected. During deceleration, the No. 3 engine disintegrated and caught fire. The aircraft did not decelerate as expected, and as it continued to roll, several tires and wheels disintegrated. As the aircraft approached the end of the runway, the captain turned the aircraft left onto a taxiway, and as it rolled to a stop, the right landing gear collapsed. The aircraft was consumed by fire which erupted on the right wing.

Since the aircraft was destroyed by fire, passenger and crew statements were used to reconstruct events inside the aircraft cabin. This flight was unique in that the 128 passengers were all employees of the carrier, including 20 flightcrew members and 93 flight attendants. All but one passenger had received varying degrees of emergency training or familiarization on the aircraft.

Although no seats failed, passengers reported that several ceiling panels were dislodged, one of which partially blocked the aisle on the left side of the cabin and exit 4L. Several oxygen mask access doors (located in the seatbacks) in the forward cabin opened during the stopping roll. Also, a movie projector at row 17 came down on its platform over the heads of seated passengers. Carry-on baggage, pillows, and blankets were thrown into the aisles, hampering passenger access to the 1R and 4L exits.

There were no fatalities, only 2 serious injuries, and 30 minor injuries--many as a result of problems encountered in using escape ropes and slides. Passengers attributed some injuries to contact with items in the cabin, such as seats, arm rests, and carry-on baggage. The aircraft was evacuated in less than 1 minute. Passengers were surprised at the speed at which fire consumed the aircraft and the short time available to evacuate. Both the crew and passengers indicated that evacuating a full load of 380 passengers would have been impossible.

With regard to survivability in this accident, the Safety Board has drawn the following conclusions:

- o The force levels were well below those cited in the regulations.
- o Even though the force levels were low, cabin furnishings failed, causing injuries, blocking exits, and hampering egress--all of which could have contributed to deaths by fire had this aircraft been fully loaded.

6/ Aircraft Accident Report: Overseas National Airways, Inc., Douglas DC-10-30, N1032F, John F. Kennedy International Airport, Jamaica, New York, November 12, 1975, (NTSB-AAR-76-19).

- This aircraft was properly certificated by the FAA; therefore, it must have successfully met all requirements. However, since failures occurred at levels below those specified in the regulations, it is likely that the methods used in certification were inadequate.

Case 3

On February 17, 1981, an Air California B-737 crashed at John Wayne Airport, Santa Ana, California. 7/ The aircraft was attempting to land on runway 19R, when it was told by the controller to go-around for another landing. The captain delayed compliance with the go-around instruction for about 12 seconds, then applied go-around thrust. The rate of descent, which was estimated to be less than 500 feet per minute, 8/ was being arrested. However, before the aircraft could begin to climb, the landing gear was improperly selected up, and the aircraft contacted the runway. The first contact was made on the landing gear. As the aircraft continued down the runway, the landing gear continued to retract. When the aircraft came to rest off the right side of the runway, both main gear and the nose gear were found in the retracted position. (See figure 9.)

A summary of passenger statements indicates that most passengers described the aircraft as touching down, lifting off, and touching down hard. This was followed by the sensation of the aircraft's sliding hard, and passengers were thrown to the left. Some passengers reported that ceiling panels fell on them and many seats failed and became detached. Four persons were injured seriously, and 29 persons were injured slightly as a result of these failures. Passengers also became entrapped by broken seats.

Documentation of the seat failures throughout the cabin indicated forces acting downward and to the left, confirming statements by the passengers. Failures occurred mainly in the seat legs; others occurred in arm rests, seat-to-floor attachments, and the seat tracks. (See figures 10 and 11.)

The flight data recorder (FDR) used in the aircraft records vertical accelerations in g's. The vertical sensor in the recorder is not designed to record crash forces, and the reading is not extremely reliable on the ground; the forces recorded on the readout are in excess of those actually experienced because of the peculiarities of this recording instrument. However, the forces recorded undoubtedly represent the maximum forces acting on the airframe below the floor at the aircraft's center of gravity. The readout of the FDR shows that the range of forces was +1.5 peak g's, indicating that the vertical forces acting on the airframe were within this range and probably considerably less. These vertical forces were well below the levels of human tolerance and well below the minimum standards set forth in 14 CFR 25.561. Even if these forces were magnified through the remaining structure to the occupant, it is unlikely that they would have surpassed the force levels cited in the regulations.

With regard to survivability in this accident, the Safety Board has drawn the following conclusions:

- The force levels in this accident were well below those cited in 14 CFR 25.561.

- Seat systems failed under combined loading downward and to the left; an event which can be detected using dynamic testing methods.

- The 4 serious and 29 minor injuries were caused by failure of seat systems and other cabin furnishings.

7/ Aircraft Accident Report: Air California Flight 336, B-737-293, N468AC, John Wayne Orange County Airport, Santa Ana, California, February 17, 1981, (NTSB-AAR-81-12).
8/ Rate of descent before touchdown was estimated from the altitude and time traces, two of the parameters recorded by the aircraft flight data recorder.

Figure 9.--Right side exterior.

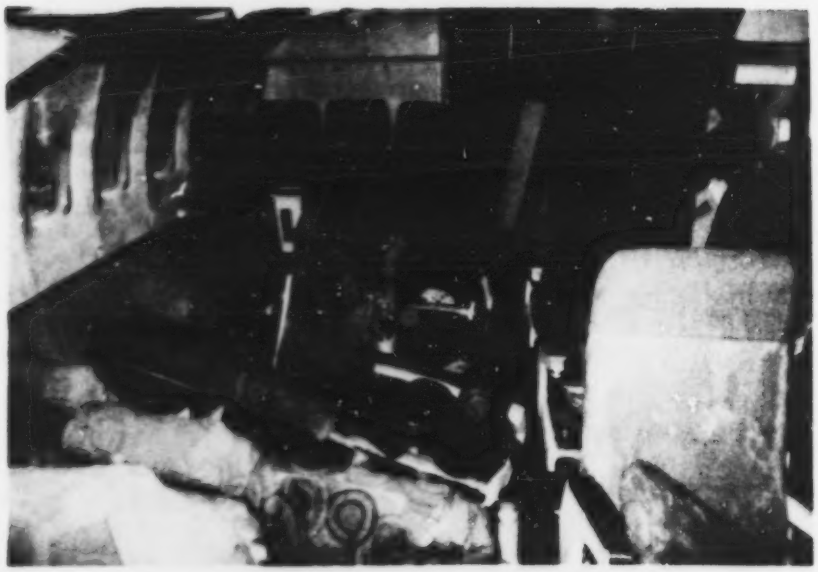


Figure 10.--Interior view to aft of cabin.

BEST DOCUMENT AVAILABLE

Figure 11.--Right side seat failure, down and to the left.
(Note jagged end of broken seat leg.)

Case 4

On December 8, 1972, United Airlines Flight 553, a Boeing 737, N9031U, en route from Washington National Airport, Washington, D.C. to Chicago-Midway Airport, Chicago, Illinois, crashed in a residential area while attempting to execute a localizer-only instrument landing system (ILS) approach to runway 31L at Midway Airport. 9/ The aircraft collided with houses, garages, trees, and power poles, and fire erupted after impact.

The aircraft came to rest with its center section entangled with portions of collapsed houses. The right side of the aircraft fuselage was destroyed from the nose to row 5 in the first-class section; the left side remained intact. The fuselage broke in two places, forward of row 6, and between rows 9 and 10--both on the right side.

Most survivors described the decelerative forces as strong enough to throw them forward against the seatbelts and badly bruise and/or cut the lower abdomen and hips. Survivors reported that debris cluttered the aisle and exit routes, making movement within the cabin difficult. Included in the debris were overhead bins, ceiling panels, luggage, seats from the left side of the coach cabin, and liquor compartment and oven units from the aft galley.

One coach flight attendant stated:

> The evacuation was hampered because the overhead bins and seats on the left hand side had collapsed blocking the aisle. The passengers who were not pinned escaped by climbing over the partially collapsed seats on the right hand side. The plane was rapidly filling with smoke and I had to run to the door . . . for air before going back in to assist the cabin. I kept shouting for passengers to get out the back of the plane and was trying to release passenger in 16B whose leg was tangled in the wreckage.

9/ Aircraft Accident Report: United Air Lines, Inc., B-737, N9031U, Chicago-Midway Airport, Chicago, Illinois, December 8, 1972, (NTSB-AAR-73-16).

BEST DOCUMENT AVAILABLE

Another coach flight attendant stated:

> I went to the buffet door and I had a great deal of difficulty opening this door because the amount of debris on the floor seemed to be blocking not necessarily my getting to the door, but getting the door opened . . . . I ran back into the cabin, as far back as I could get into the cabin. The seats had become dislodged in the area that I could see and the ceiling had collapsed. . . . you could not see anything on the right hand side of the aircraft. The left hand side was just a jumble of seats.

To the extent that seat locations of survivors before impact could be established, no distinct survivability pattern emerged. Of the 61 persons on board, 43 were killed. Of these, 27 died of fire-related causes. About 27 percent of the first-class passengers, and 76 percent of the coach passengers died from fire or smoke and toxic fumes.

With regard to survivability in this accident, the Safety Board has drawn the following conclusions:

- o The g-levels experienced by occupants in this crash were relatively high, but still well within the limits of human tolerance for most of the locations in the cabin.

- o The number of fire-related deaths, which were likely the result of incapacitation or entrapment, probably could have been reduced significantly had seat systems and other furnishings been designed and tested to upgraded standards.

Case 5

On March 3, 1972, Mohawk Airlines Flight 405, an FH-227B, N7818M, en route from La Guardia Airport, New York, to Albany, New York, crashed while attempting to execute a localizer backcourse ILS approach to runway 01 at the Albany County Airport. 10/ The aircraft hit a house about 4 miles from the airport and came to rest within the confines of the residence. There was no fire. (See figure 12.)

The aircraft penetrated the right front of the house and stopped with the nose protruding about 25 feet from the back of the house and with the fuselage resting in the basement area. The nose of the aircraft was crushed back to the windshield, causing the instrument panel to be displaced to the front edge of the flightcrew's seats. The bottom of the fuselage was demolished and the cabin floor was split longitudinally for almost the full length of the fuselage. Each side of the floor where the seat tracks were attached was displaced upward. The occupiable cabin space was compromised to the extent that there was a severe elliptical deformation in the fuselage cross section for most of the fuselage length. (See figure 13.)

Cabin side panels came loose because of the downward compression of the fuselage ceiling. Both overhead racks had separated from their attach points. Although the galley remained intact, it separated from its upper attach points and its contents were scattered inside and outside of the cabin. Most seats separated from the structure at impact. Primary failures were in the seat support structures, just below the leg attachment to the

10/ Aircraft Accident Report: Mohawk Airlines, Inc., Fairchild Hiller FH-227B, N7818M, Albany, New York, March 3, 1972, (NTSB-ARR-73-8).

Figure 12.--Aircraft lodged in house.

Figure 13.--Aircraft after house was torn away.

BEST DOCUMENT AVAILABLE

seat chassis. The failures consisted of bending or complete fracture of the seat legs in both the downward and sideward directions. (See figure 14.)

In addition, the front seat-to track attach fittings, seat backs, seat pans, and arm rests failed. The seat back tray tables, although damaged to varying degrees, remained latched in most cases. The seat tracks also exhibited various degrees of failure throughout the cabin.

Of the 48 persons on board, 16 were killed, and 32 were injured seriously. Generally, the fatally injured persons exhibited skull fractures, spinal fractures, brain damage, ruptured aortas, crushed chests, fractured ribs, and fractured extremities. The survivors exhibited injuries such as spinal injuries, which occurred in 18 cases, concussions, fractures of the skull, face, ribs, sternum, clavicle, arm, and pubic bone, and various other internal injuries. Ankle and leg fractures were suffered by 19 survivors. Only one survivor escaped from the aircraft unaided. All injuries were attributed to the loss of restraint caused by failure of the tiedown chain.

The flight attendant seat which failed was designed for load factors of 9.0g forward, 6.5g downward, and 1.5g sideward. The passenger seats were designed for load factors of 9.0g forward, 7.5g downward, and 3.0g sideward. A study of the forces generated by the aircraft's impact with the residence gave estimated forces of 15 to 25g forward, 5 to 15g downward, and 5 to 10g sideward.

Figure 14.--Typical failure mode of passenger seat. (Note direction of failure of seat legs and left arm rest of this left hand seat unit.)

BEST DOCUMENT AVAILABLE

With regard to survivability in this accident, the Safety Board has drawn the following conclusions:

- This was a severe accident with forces approaching but not exceeding the limits of human tolerance to acceleration for occupants restrained only by a seatbelt.

- Although the fuselage was deformed and the floor was split up the middle for almost the entire length of the cabin, the floor structure on each side with the floor tracks attached stayed essentially intact and should have been capable of retaining the seats with the occupants.

- The seats failed under combined loading in the downward and sideward directions which is a foreseeable event that can be detected under dynamic test conditions and corrected.

- All of the injuries sustained in this crash were typical of those caused by high velocity impacts after loss of restraint.

- If fire had occurred, all but one survivor would have died.

In summary, the following general conclusions were drawn from the five case histories:

- Failures of cabin furnishings and seats are occurring in different types of accidents regardless of severity.

- Some seats are designed for loads in excess of those required by FAA, but less than those estimated to have occurred in these accidents.

- Failures of seats and furnishings injure, trap, and incapacitate occupants, and create obstacles to egress.

- Because of unpredictable postcrash factors such as fire, time to escape is limited severely.

- Aircraft fuselages are able to provide adequate protection to the occupants even in the more severe accidents.

- Seats and other cabin furnishings are failing under combined loads acting in different directions simultaneously.

- Occupants are surviving the higher crash forces, but are receiving fatal impact injuries caused by loss of restraint, or are dying needlessly in postcrash fire because injuries or entrapment preclude escape.

- There is a demonstrated need to design the tiedown chain and other cabin furnishings for higher loading conditions which are more representative of actual crash experience.

DISCUSSION

Regulations and Standards

The regulations dealing with the ability of an aircraft to withstand crash forces are found in two different subparts of 14 CFR 25, Airworthiness Standards: Transport Category Airplanes. For cabin crashworthiness and occupant protection, the specific regulations are 14 CFR 25.561, Emergency Landing Conditions--General; 14 CFR 25.785, Seats, berths, safety belts, and harnesses; 14 CFR 25.787, Stowage compartments; and 14 CFR 25.789, Retention of items of mass in passenger and crew compartments and galleys.

The most important regulation in this group, 14 CFR 25.561, is the foundation for the other three regulations. It has two main sections, one of which deals with forces felt by the occupant and one of which concerns the retention of cabin furnishings.

Forces on the Occupant.--The regulation (14 CFR 25.561) states that the structure must be designed so that it gives each occupant "every reasonable chance of escaping serious injury in a minor crash landing" when three conditions are met. The first condition is that proper use is made of the seats, seatbelts, and other safety provisions. The second condition is that the aircraft's wheels are retracted if the aircraft has retractable gear. The third condition is that the forces experienced by the occupant and "acting separately relative to the surrounding structure" are equal to or less than 2.0g upward, 9.0g forward, 1.5g sideward, and 4.5g downward. The regulation further states that a lesser force in the downward direction may be used. This is the force which will not be exceeded when the aircraft absorbs the loads which result from an impact, at design landing weight, with a descent velocity no greater than 5 feet per second (300 feet per minute).

This regulation, in effect, defines a "minor crash landing;" that is, a wheels-up landing for aircraft with retractable gear at a reduced rate of descent on a level surface, such as a runway, with no obstacles. However, typically, aircraft involved in crashes encounter some obstacles, even those which crash on runways, and many aircraft crash over uneven terrain. Also, few wheels-up landings occur with these types of aircraft. Therefore, the accident described in the regulation does not represent adequately the real-world accident environment.

Accident experience has shown that humans survive in crashes that involve relatively high forces. Recognizing that human tolerance limits are considerably higher than the load limits cited in 14 CFR 25.561, two other factors become apparent. First, the current fuselage structures are doing a relatively good job of protecting occupants in crashes with large forces. Second, the limiting factor for survival in these crashes is not human tolerance limits; instead, it is the lethal nature of the environment inside the fuselage.

The use of cadavers, animals, dummies, or even the best computer models cannot reproduce exactly the reactions of live humans to various acceleration forces, and the obvious dangers involved in using human volunteers for these studies make it unlikely that much new knowledge of human tolerance will be gained in the near future. However, the Safety Board believes that sufficient data already exists in this area to support and substantiate design and development of environments that will be better able to protect the occupants of aircraft under a broad range of crash conditions.

Retention of Cabin Furnishings.--Retention of cabin furnishings is dealt with in a limited way in the second part of 14 CFR 25.561. In the regulation, furnishings are referred to as "items of mass." The regulation states that the supporting structure for each of the items of mass that could injure an occupant if it came loose in a crash landing must restrain these items. Thus, these items must be restrained only to the loads cited--9.0g forward, 4.5g downward, 1.5g sideward, and 2.0g upward.

In 1972, the regulations were amended to deal more comprehensively with the retention of items of mass in both passenger and crew compartments and galleys. The new regulation, 14 CFR 25.789, requires that some means be provided to keep the items of mass from becoming hazards by shifting when subjected to maximum load factors under specified flight loading and ground loading conditions, as well as the loads in 14 CFR 25.561. It also requires that each interphone remain in its stowed position when subjected to the loads specified in 14 CFR 25.561. The ground load criterion deals with the conditions under which the landing gear and aircraft structure must withstand specified inertia loads in the downward, forward, and sideward directions experienced in normal ground operations. The flight load criterion relates to the aerodynamic load criterion acting on the aircraft for specified aircraft weights and altitudes in the normal operating envelope.

Stowage compartments located in the cabin, in which such items as cargo, baggage, emergency and other equipment, and carry-on articles are stowed must also be designed to withstand the loads specified by 14 CFR 25.787 in addition to those specified in 14 CFR 25.561. Each of these compartments must be designed to retain its maximum allowable weight under these load factors. The regulation also states that there must be a means to prevent the articles in these compartments from shifting and becoming hazards within the specified loads.

Accident experience has shown that stowage compartments do not meet the intent of the regulation to keep their contents from becoming hazards by shifting when subjected to the specified ground, flight, and crash forces. The accident and incident cases cited in this study show that objects are released from the compartments, injuring occupants and hampering egress.

The last major regulation dealing with the design of cabin furnishings, 14 CFR 25.785, deals with seats, berths, safety belts, and harnesses. The regulation begins by reiterating the requirement in 14 CFR 25.561, which states that these items must be designed so that a person making proper use of the safety equipment will not be injured seriously in a crash landing as a result of the forces specified in 14 CFR 25.561. It further states that each occupant must be protected from head injury by a safety belt and at least one of the following: (1) shoulder harness (2) the elimination of injurious objects within the strike envelope of the head, and (3) an energy absorbing rest that is capable of supporting the head and upper torso.

The regulation states that the determination of the strength of the attachment of the seat to the structure and the attachment of each belt or harness to the seat must at least be equal to the forces specified in 14 CFR 25.561 mutiplied by a factor of 1.33. This means that while the passengers may be allowed to feel the specified inertia loads, the seat and seatbelt connections must withstand forces one-third greater.

Accident experience has also shown that the requirement of 14 CFR 25.785 to provide protection for each occupant from head injury is not being met. In typical fixed-wing, nonmilitary transport aircraft, forward facing seats are used, and the typical accident involves forces applied mainly from the front. In such cases, it is not feasible to protect the occupant with an energy absorbing rest to support the head and upper torso. Also, in seats other than those for the crew, no shoulder harnesses are available, leaving only the possibility of protecting passengers by eliminating injurious objects within the strike envelope of the head.

Figure 15 shows the strike envelope of a 95th percentile army aviator, restrained by lap belt only. Although the body measurements are not representative of the airline

passenger population as a whole, they probably represent at least part of the upper percentiles of the aircraft passenger population in terms of size and weight. In this case, the head will travel through an arc where maximum extension is about 45 to 50 inches forward of the seat back. The seat pitch (the distance between similar points on seats in the next row forward or behind, measured horizontally) in air transport aircraft averages about 32 inches. Figure 16 shows the relationship of the strike envelope to seat position in this case. With a lap belt only, the seats become injurious objects within the head strike envelope. This would also be true for individuals whose statures are less than that of the 95th percentile model. Notice also the flailing envelope of the arms and legs. Injuries to these extremities incapacitate occupants so that they are unable to easily release their seatbelts because of arm and hand injuries, or to evacuate the aircraft because of leg and foot injuries. Flailing body extremities which contact other seats also contribute to the loads acting on those seats, increasing the chances of the seats failing. 11/

Tests on head impact tolerance have shown that the force levels necessary to cause skull fractures generally are high. Spread over a 3-square-inch area of the forehead, forces of about 200g or greater can be tolerated. Considerably higher levels can be tolerated if the impact is spread evenly over the entire face. However, skull fracture is only one type of injury which can occur when the head strikes an object during acceleration. Internal head injuries, such as concussion, can occur with or without skull fracture and are more difficult to measure. 12/ Even with seat backs padded with energy absorbing material, the head and face can still be injured. FAA studies 13/ have shown that head velocities in 8g crash decelerations can reach 50 feet per second, and that padding commonly used on seats is insufficient to protect passengers against head injury. Although the seatbacks in transport aircraft are designed to fold forward when 35 pounds of pressure are applied, injuries are still occurring when occupants strike seatbacks. The accidents cited in this study as well as others have demonstrated this point. Although not all of these injuries are serious, requiring extended hospital stays, they can cause at least temporary incapacitation, which may lead to death because of postcrash factors.

An individual is much better protected from head injury with the shoulder harness, even with a reduced seat pitch. (See figure 17.) In addition, the occupant's tolerance to forward acceleration would be increased greatly.

In summary, the Safety Board concludes that occupants of large transport aircraft are not protected adequately in a minor crash landing. Further, the Safety Board concludes that 14 CFR 25.561 does not represent adequately the actual accident experience of transport aircraft, and that because of this, the passengers and crew are not receiving protection in survivable and partially survivable crashes where it is most needed.

This study has shown that aircraft occupants are being injured, trapped, and killed in survivable accidents. Many deaths and injuries are directly attributable to failures of seats and cabin furnishings. However, most of these accidents involved forces greater than those specified in 14 CFR 25.561. For these cases, the failures are to be expected, even if the minimum standards for design are met.

11/ Swearingen, J.J., Hasbrook, A.H., Snyder, R.G., McFadden, E.B. Kinematic Behavior of the Human Body During Deceleration, 62-13, FAA Civil Aeromedical Research Institute, June, 1962.
12/ Hodgson, Voigt R., and L.M. Thomas, "Head Injury Tolerance," Aircraft Crashworthiness, Saczalski, et. al., The University Press of Virginia, 1975.
13/ Swearingen, John J., Evaluation of Various Padding Materials for Crash Protection, AM 66-40; General Aviation Structures Directly Responsible for Trauma In Crash Decelerations, FAA-AM-71-3, FAA Office of Aviation Medicine.

BEST DOCUMENT AVAILABLE

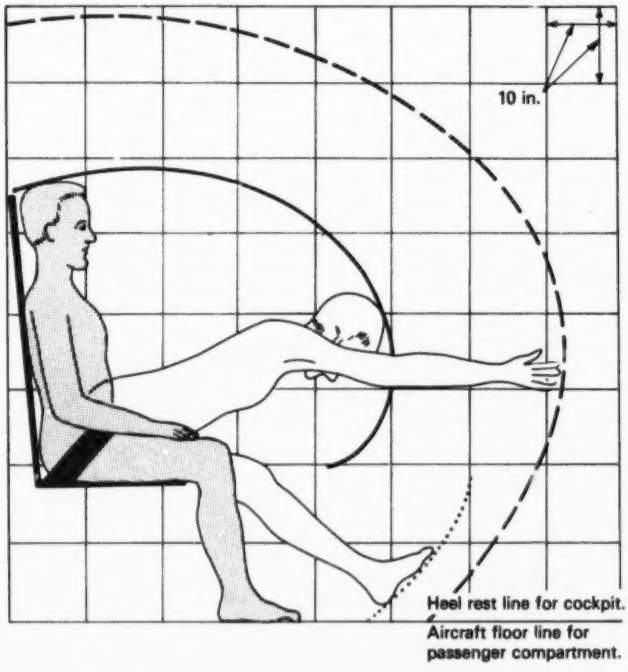


Figure 15.--Lap-belt-only extremity strike envelope-side view.
(From Crash Survival Design Guide, USARTL-TR-79-22.)

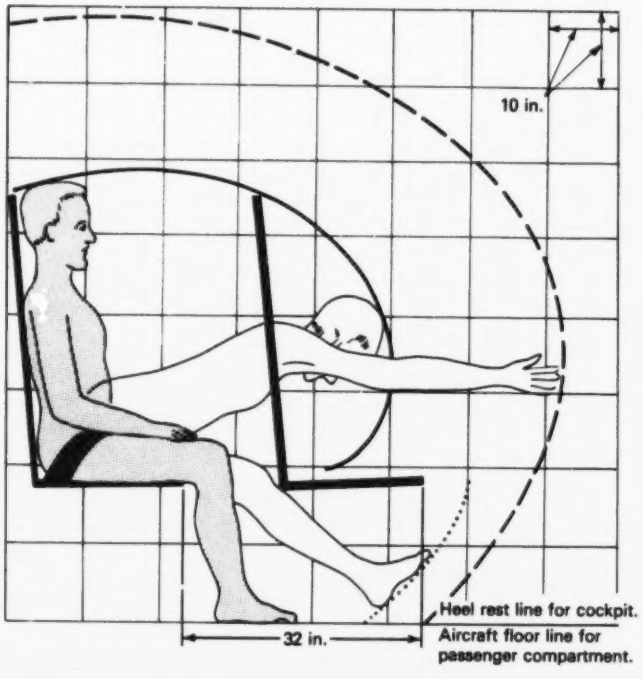


Figure 16.--Lap-belt-only extremity strike envelope-side view.
(From Crash Survival Design Guide, USARTL-TR-79-22.)

BEST DOCUMENT AVAILABLE

The FAA has stated repeatedly that humans cannot withstand forces much greater than those for which seats are presently designed, 14/ and has used this assumption as part of its argument for not upgrading seat standards. As this study has shown, there is ample evidence from accident cases as well as research to show that human tolerance levels are significantly greater than the FAA officially maintains. The evidence includes a substantial body of work done within the FAA itself. Most of the accident cases in this study have indicated that the limiting factor in survival is not human tolerance to crash forces, but rather the lethal nature of the aircraft interior and the inability of the tiedown chain to restrain the individuals.

The Safety Board believes that treating crashworthiness and occupant protection in separate subparts of 14 CFR 25 and not in one consolidated section also has contributed somewhat to the lack of progress in this extremely important area. The regulations pertaining to these areas are now found in various sections of 14 CFR 25 under different headings of the following subparts.

Subpart C - Structure
    Emergency Landing Conditions
Subpart D - Design and Construction
    Personnel and Cargo Accommodations
    Emergency Provisions
Subpart F - Equipment
    Safety Equipment

The fact that the FAA has never consolidated these regulations into a single subpart, or placed any other emphasis on crashworthiness, may have contributed to the reluctance of industry to incorporate new technology or to take advantage of crashworthiness design philosophies. The Safety Board believes that creating a single subpart for crashworthiness and occupant protection would reflect the increased emphasis by the FAA on this important aspect of aircraft design and construction. Further, regulations concerning safety and occupant protection could be consolidated and coordinated.

Design Technology

The Safety Board did not attempt to gather and evaluate all available design and testing technology, since it is not its role to attempt to provide specific solutions for the engineering problems disclosed by its investigations. The Safety Board believes that the following summary clearly illustrates that improvements in designing and testing aircraft cabin components can be made.

Perhaps the best summary of current design technology for seats and restraints is Volume IV of the Aircraft Crash Survival Design Guide. The guide presents a philosophy and goals of crashworthy seat and restraint design and gives an overview of the methods available to accomplish these goals. It critiques different methods, test results, and results of actual experience. Although the design guide was intended for use primarily on light fixed- and rotary-wing aircraft used by the military, the technology is transferable to larger aircraft.

14/ One of the most recent of those statements was made in hearings before the Subcommittee on Oversight and Review of the Committee on Public Works and Transportation, House of Representatives, June 3-5, and September 10, 1980, and is in report 96-60, "Cabin Safety: "Safer Committee" Update (Aircraft Passenger Seat Structural Design)."

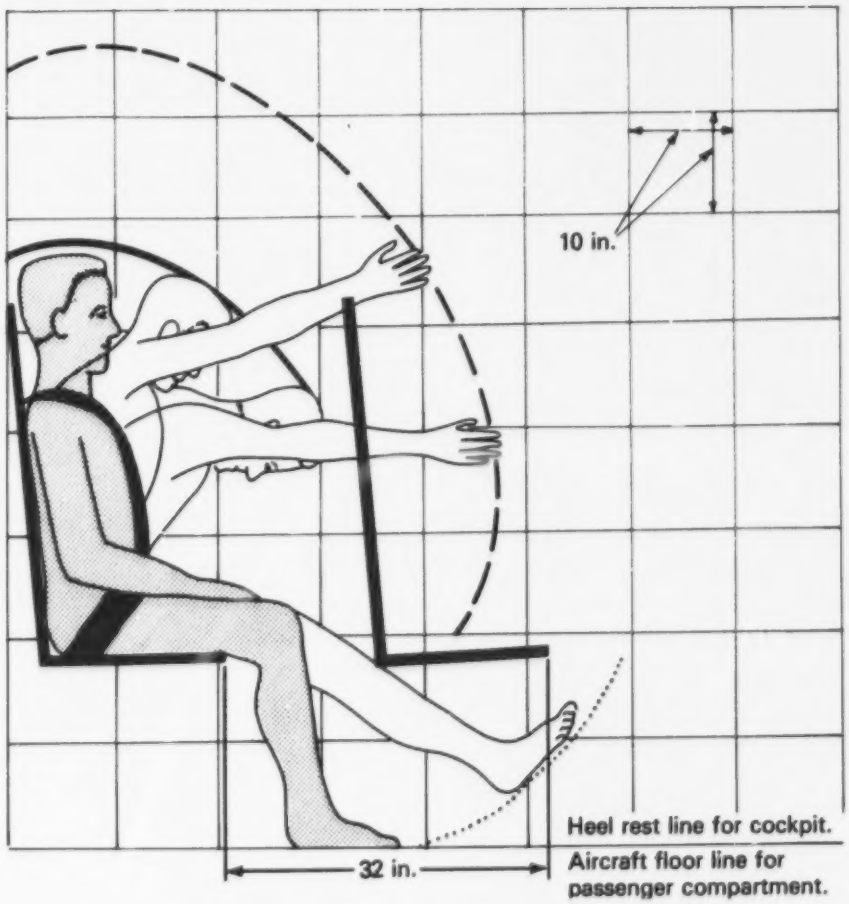


Figure 17.--Full-restraint extremity strike envelope-side view. (From Crash Survival Design Guide.)

With regard to the choice of proper materials in design, the Guide recommends that materials with good strength-to-weight ratios and high ductility be used. In choosing materials to enhance crashworthiness, their behavior after permanent deformation begins is important.

Different types of structural connections are also discussed. Tiedown chain failures caused by floor distortion, bulging, or warping are identified as major problems in crashes of transport aircraft. One of the design configurations presented to accommodate these distortions is the use of a "plastic hinge" at the seat-to-floor track attach point. The hinge is actually a highly ductile material which will deform without failure up to a certain point as the floor is displaced. Another design modification suggested is the use of a ball and socket joint at the seat-to-floor track attachment. These and other methods presented are all designed to allow the seat and occupant to remain in place while the floor is displaced. Design methods are provided for floor-mounted, bulkhead-mounted, and sidewall-mounted seats, all of which are used in transport aircraft.

BEST DOCUMENT AVAILABLE

Critical parts of the tiedown chain include the floor and subfloor structures. These must be compatible with the seat design so that high stresses will not be concentrated in one area, causing premature failure. In 1963, studies 15/ of the tiedown chains in three U.S. Army aircraft showed that the crash strength of these systems could be improved by a factor of 2 while adding only a small amount of weight. One of the improvements was in the strength of the floor tracks, a major problem in transport aircraft crashes. Studies suggested putting small aluminum collars on the seat track tiedown bolts between the nut and the floor. The collars, which compressed before the bolts broke, helped to spread the load and allow the seat tracks to deform without failures up to twice the ultimate tiedown strength before installation of the collars.

Energy absorption in a crash is a combination of the crushing of the airframe, landing gear, and landing surface. In many cases, however, there is a large amount of energy remaining, which will be transmitted to the occupant. This additional energy may be absorbed by the seat through the use of load-limiting or energy-absorbing devices. These devices are set to preselected values. In a crash, they absorb energy by providing a resistive force over a certain distance, allowing the occupant to come to a stop over a longer distance and thereby decreasing the average load acting on the occupant. Information on and comparisons of nine of the most common of these devices are provided in the Guide. Information from research conducted by Government and industry on load-limiting devices is also provided.

The Guide also provides information on types of restraint systems and methods of installation. It explains that when a shoulder harness is used, but lap belt tiedown straps are not used and the seatbelt anchor point is not correct, force on the shoulder harness can pull the lap belt up, allowing the occupant to submarine, or slide under the belt, causing injuries. Submarining can also occur when only a lapbelt is used and the anchor point is not correct. The FAA has cited these injuries to demonstrate that human tolerance to acceleration when restrained by lap belt only is relatively low. This, in fact, demonstrates only how poorly designed restraint systems can add to injury.

As pointed out in this study, if cabin furnishings fail in a crash, the furnishings or items released from them can become missiles in the cabin. They can cause injury directly by striking occupants, or they can block egress paths. They can also strike seats, imposing even greater loads on them and thereby induce failures in the occupant restraint systems. For these reasons, it is important that these furnishings, or items of mass, be restrained to loads equal to or greater than those of the seats. In most cases, this should not cause a problem in design or impose penalties of additional weight. For heavier items, however, the use of load-limiting devices like those for seats is recommended.

Testing Technology

The accident cases presented in this study have shown that crash environments are extremely complex and variable during the crash sequence. Forces acting on the aircraft and its interior do not act separately, but in various and unpredictable combinations. For some time, the Safety Board has advocated the use of dynamic testing of items in the tiedown chain and other items of mass in the aircraft cabin. 16/

15/ Haley, J.L., Jr., and Avery, J.P., Ph.D., Personal Restraint Systems Study - HC-1B Vertol Chinook, AvCIR 62-26; HU-1A and HU-1B Bell Iroquois, AvCIR 62-27; CV-2 de Havilland Caribou, AvCIR 62-16, Aviation Crash Injury Research (AvCIR), Division of Flight Safety Foundation, Inc., Phoenix, AZ.

16/ The Board has made the following safety recommendations on this subject: Recommendation Number 63-33 (November 8, 1962), Recommendation Number CY 70-42 (August 28, 1970), Recommendation Number A-75-051 (June 2, 1975), and Recommendation Number A-80-131 (December 17, 1980).

Regulation 14 CFR 25 provides basic information on the minimum standards these items are to meet, and 14 CFR 21 (formerly 14 CFR 37) provides the specific requirements. This part, titled "Technical Standard Order Authorizations," prescribes the minimum performance standards and quality control standards for various articles used on aircraft through the use of Technical Standard Orders (TSO). Aircraft safety belts and seats are regulated under this part. For these aircraft cabin furnishings, only static testing is required. Static testing is used to verify that the system and its components possess the required strength and other desired properties in the principal loading directions. The response of the system or its components can be observed as the forces are applied slowly. TSO-C39a describes the minimum performance standards for seats and berths. For methods used in testing the seats, it refers to National Aircraft Standard (NAS) 809, which was approved in 1956 and has not been revised since. Seatbelt performance is governed by TSO-C22f, which refers to NAS 802, last revised in 1950.

Under the prescribed test methods, the applied loads during seat testing are assumed to be acting separately in each major direction. While these forces may be evaluated in combination, it is not required. Also, there are no provisions or requirements for statically testing the seats under conditions which simulate floor warping.

A more realistic test environment is provided by dynamic testing. Some materials react differently to forces applied rapidly under dynamic test conditions than they do to slowly applied forces. Under dynamic conditions, unexpected failures may occur which could not be predicted on the basis of static test results. There are different types of dynamic testing, however. In general, both industry and the FAA, which has done much research on dynamic test methods, refer to unidirectional dynamic tests. While providing a much improved idea of seat response under crash conditions, unidirectional testing still does not adequately replicate actual crash dynamics.

The Design Guide describes a method for dynamically testing seat systems in more than one axis simultaneously. The Safety Board believes that this is the best method currently available for dynamic testing, because it involves the components of the seat system reacting together under conditions in which forces are applied simultaneously from different directions. This type of force application represents more accurately the environment in an actual crash.

As noted, the requirements for design and testing of seats and restraints presented in the Design Guide are for use specifically in light aircraft, both fixed- and rotary-wing. Requirements for larger aircraft differ somewhat because of the increased amount of crushable space beneath the seats, and the overall mass of the aircraft. Simula Inc., which prepared the latest revision of the Design Guide, has distributed a paper describing a seat system design and test regime for transport category aircraft. (See appendix B.) This paper was submitted to the FAA's official docket in response to its 1980 hearings on transport aircraft seat strength. It discusses requirements for three size categories of aircraft, based on the amount of crushable space available in each category. As aircraft size increases and more space is available below the floor to crush and absorb energy, less energy must be absorbed by the seat. Thus, there is a need for differing requirements.

The first of the categories is small aircraft, usually having a capacity of less than 50 passengers, which have less than 36 inches of crushable space below the floor. The second category is medium size aircraft, generally holding from 50 to 249 passengers, which have more than 36 inches but less than 60 inches of crushable space. The final category is large aircraft with a seating capacity of 250 or more passengers, which have more than 60 inches of crushable space. The following tabulation provides the test requirements suggested for use by Simula Inc., in each category.

Parameter	Small (Less than 36 in.)	Medium (36-60 in.)	Large (More than 60 in.)
Time (sec)	0.109 - 0.1[illegible]	0.128 - 0.140	0.155 - 0.175
G's	19 - 22	17 - 20	14 - 16
Minimum velocity change (ft/sec)	50	50	50

These requirements are measured in two tests. The first test is to ensure that the vertical load-limiting capabilities of the seat system operate satisfactorily under conditions of simultaneous forward and sideward loading. The second test is to ensure that the seat system is able to withstand the design pulse forces when applied simultaneously in the forward and sideward directions. These design and test methods can be applied to all transport category aircraft covered by this study as well as the smaller transport aircraft, all of which are regulated by 14 CFR 25.

Crashworthiness Work

In the early 1960's, FAA and other Government agencies, including the military, cooperated with industry in a series of contract studies of crashworthiness. These studies added to and expanded the concepts and knowledge gained in the 1940's and 1950's. Part of this work included full scale crash tests of a Lockheed Constellation and a Douglas DC-7, both of which contained various experiments including experiments dealing with seats, restraints, and the overall acceleration environment. Much of the information from these tests and previous research and development were incorporated into the first Crash Survival Design Guide, published in 1967. 17/ Both Government and industry actively disseminated the new information on various aspects of crashworthiness to the public. A substantial number of these papers were published by FAA in the late 1960's, many of which included recommendations for upgrading the minimum standards of 14 CFR 25.561. However, FAA did not change the regulations based on the results of these studies. The design and test methods are used on a regular basis only by the Army. The crashworthiness design principles proved to be so effective that the Army turned many of them into contract requirements for all of its aircraft.

In the previously referred to FAA 1980 hearings on seat strength, testimony was given based in part on the results of the crash tests of the Constellation and DC-7 and on other crash information, including more recent data on jet aircraft. The FAA expressed reluctance to accept the validity of the testimony as it relates to the accident experience of today's air carrier fleet. The reasoning behind this apparent reluctance was that the designs of modern aircraft and the materials used in them differ substantially from those of the large piston-powered and older turboprop-powered aircraft. Therefore, the FAA concludes, the structures will react differently in a crash.

The FAA is once again working with other Government agencies and industry to define crash scenarios and failures or inadequacies in structures which lead to injury or death in crashes and to identify candidate areas for further research and development programs. This current crashworthiness program was started in 1980 and is scheduled for completion at the end of 1985. The culmination of the program will be the full-scale crash test of a Boeing B-720 aircraft. This will include the test of a currently manufactured airline seat which will be modified by Simula Inc., to include load attenuating devices.

17/ Original edition of the Aircraft Crash Survival Design Guide cited previously in this study.

Although it should be possible to conduct many worthwhile experiments and to gather new data in this test, the Safety Board questions whether the FAA will be any more willing to accept such crash data as being representative of modern aircraft. The type certificate of the B-720 was applied for on April 12, 1957, only 7 years after the DC-7 type certificate application. The regulations in effect on that date are those that the aircraft was required to meet. In this case, they were CAR 4b - Airplane Airworthiness Transport Categories, the forerunner to the current Part 25 of the Federal Aviation Regulations (14 CFR 25).

Physically, the B-720 resembles a B-707. Like the Constellation and DC-7, it is a narrow body aircraft with four wing-mounted engines. Although they are jets mounted under the wing instead of piston engines mounted in the wing, the overall weight distributions of these aircraft are similar. Since the B-720 operates at higher altitudes, the difference between cabin pressure and outside pressure is greater; therefore, its fuselage is probably stronger in this area. However, these aircraft are all made of essentially the same materials.

Many of the more modern aircraft are wide bodied and have at least one tail-mounted engine, which gives them different weight distributions. Perhaps even more important is the fact that the materials used to build modern aircraft are changing rapidly. More and more, advanced composite materials are being used to fabricate major structural components of the aircraft. Composites are also being used in the aircraft interiors for seats and other structures. Although studies on the crash characteristics of smaller composite structures are now being studied, little is known about how larger composite structures will react in a crash. Also, little is known about reactions of composite cabin furnishings, such as seats, in a crash. 18/

A new generation of aircraft which make more extensive use of composite structures is already in production and the FAA's current crashworthiness program will investigate some of the areas dealing with new structures. Assuming that this current program stays on schedule and provides what the FAA considers sufficient data to support rulemaking, it is highly unlikely that any changes in the regulations will occur before 1990. Assuming that a new or amended regulation becomes effective on that date, it will affect only those aircraft making initial application for type certificates on or after that date. With an average of about 4 years between type certificate application and final approval, it is unlikely that major improvements in aircraft crashworthiness based on the current program will be seen much before the year 2000, another 20 years. Morever, the Safety Board is concerned that, since this crash test will add only one more data point to an already established data base which the FAA has previously rejected as adequate evidence to support rulemaking, the FAA's reluctance to upgrade the crashworthiness regulations will continue.

The Safety Board believes that there is sufficient data currently available to support the upgrading of the occupant crash protection standards in the regulations; and further, that the substantial body of knowledge and practical experience in design, construction, testing, and use of crashworthy structures and cabin furnishings can be applied successfully to large transport aircraft, in many cases without substantial penalties in cost or weight and without major modifications to existing structures. The Safety Board also believes that the FAA should concentrate its efforts on applying available technology to transport aircraft, and in newer areas, such as crashworthiness of composites, instead of continuously reevaluating past work that has been proven valid through actual use for at least 10 years, in both the aviation and automotive industries.

18/ A compilation of data on composite structures recently published by the Army is in Investigation of the Crash-Impact Characteristics of Advanced Airframe Structures, USARTL-TR-79-11, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia.

CONCLUSIONS

1. Seat systems and other cabin furnishings are failing in accidents/incidents where the acceleration forces acting on the aircraft and occupants are less than the design forces prescribed by 14 CFR 25.561.

2. Human tolerance to abrupt accelerations when restrained by lap belt only is two to three times greater than the force levels cited in 14 CFR 25.561.

3. Most of the survivable and partially survivable accidents/incidents analyzed in this study involve acceleration forces acting on the aircraft and occupant that are in excess of the levels cited in the regulations.

4. The fuselage structure of current aircraft is able to provide adequate protection for occupants in accidents involving forces considerably in excess of the requirements of 14 CFR 25.561.

5. Aircraft occupants are being injured and killed because of the failure of seat/restraint systems and other cabin furnishings in survivable and partially survivable accidents.

6. Failed seat systems and cabin furnishings trap occupants or become obstacles to rapid egress, thereby increasing greatly the potential for fatalities caused by postcrash factors.

7. The regulations and standards governing crashworthiness of cabin furnishings have not been upgraded for about 30 years.

8. Consolidation of the crashworthiness regulations in one subpart of 14 CFR 25 could contribute to progress in this area.

9. There is sufficient data currently available regarding human tolerance and crashworthiness to demonstrate the need for and the feasibility of upgrading the applicable regulations.

10. Crash scenarios are extremely complex and forces on the aircraft and its interior act from several directions simultaneously and in unpredictable combinations.

11. In addition to the inability of static testing to prove the adequacy of seat systems under dynamic conditions, the tests do not include consideration of conditions of warping and buckling of seat attachment structures, such as floor, side panels, and bulkhead.

12. Available crashworthiness design and testing technology should be implemented and should be upgraded periodically as state-of-the-art improves.

13. Requirements for multiaxis dynamic testing should be incorporated into seat system design and certification criteria.

14. Padding of aircraft interiors is insufficient to protect passengers against head injuries in these crashes.

15. Human tolerance to forward acceleration can be increased greatly, and head injury potential can be reduced greatly, by use of upper torso restraint.

16. The major emphasis of FAA's ongoing crashworthiness programs should be on applying available technology, and on improving state-of-the-art technology rather than reexamining proven technology.

17. Obstacles in the airport environment such as ditches, dikes and embankments, and nonfrangible structures, needlessly increase the severity of many accidents/incidents occurring on the airport.

RECOMMENDATIONS

As a result of this special study, the National Transportation Safety Board made the following recommendations:

--to the Federal Aviation Administration:

Establish a separate single subpart in 14 CFR 25 which consolidates crashworthiness requirements for transport category aircraft pertaining to areas such as crash models, occupant protection requirements, emergency egress, retention of items of mass, and seat and seat restraint systems. (Class III, Priority Action) (A-81-139)

Revise the crashworthiness requirements as presently described under Emergency Landing Conditions, 14 CFR 25.561, to eliminate reference to the term "minor crash landing," and to include a descriptive crash model determined from FAA's Transport Aircraft Crashworthiness Program. (Class III, Priority Action) (A-81-140)

Establish and specify in the appropriate subpart of 14 CFR 25, interim standards for the design of seat and restraint systems and cabin furnishings to withstand the multiaxis acceleration levels such as those described by Simula Inc. in its Paper TI-8017. (Class II, Priority Action) (A-81-141)

Establish and specify in the appropriate subpart of 14 CFR 25 and in the related Technical Standard Orders, interim standards for static and dynamic testing of seat/restraint systems, including consideration of warpage or buckling of the attaching structure, and multiaxis dynamic pulses such as those described by Simula Inc. in its Paper TI-8017 and in the Aircraft Crash Survival Design Guide. (Class II, Priority Action) (A-81-142)

Establish an internal procedure which will ensure the periodic review of state-of-the-art crashworthiness design and testing technology and will reflect the improved technology through upgraded standards. (Class II, Priority Action) (A-81-143)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JAMES B. KING
Chairman

/s/ PATRICIA A. GOLDMAN
Member

/s/ G. H. PATRICK BURSLEY
Member

ELWOOD T. DRIVER, Vice Chairman, and FRANCIS H. McADAMS, Member, did not participate.

September 9, 1981

BLANK PAGE

APPENDIXES

APPENDIX A

DEFINITIONS OF PHASES OF FLIGHT OPERATION

Taxi - From the time the aircraft first taxies under its own power until taking the active runway. Also, when the aircraft taxies off the runway until it parks at the spot of engine shutdown.

Takeoff - From the time the aircraft enters the runway up to and including the first airborne power reduction.

Climb - From the time of initial power reduction until the aircraft levels off at its cruise altitude.

Cruise - From level off at cruise altitude to departing cruise altitude.

Descent - From the beginning of the descent from cruise altitude to the Initial Approach Fix (IAF), Final Approach Fix (FAF), Outer Marker, or Visual Flight Rules (VFR) pattern entry whichever occurs first.

Approach - From the time the descent ends (either the IAF, FAF, Outer Marker, or VFR pattern entry) until the aircraft reaches the Missed Approach Point (MAP) under Instrument Meteorological Conditions (IMC), or runway threshold under Visual Meteorological Conditions (VMC). Includes missed approach (IMC) and go-around (VMC).

Landing - From either the MAP (IMC) or runway threshold (VMC) through touchdown until aircraft taxies off the runway.

APPENDIX B

October 13, 1980

TI-8017

TRANSPORT CATEGORY AIRCRAFT SEAT STRENGTH PROPOSED MODIFICATION TO FAR PART 25

Prepared by:

S. P. Desjardins
and
D. H. Laananen

Simula Inc.
2223 S. 48th Street
Tempe, Arizona 85282

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

1. INTRODUCTION

On the following pages are presented requirements for seat strength and the tests to be conducted in verifying those strengths. Occupant weights to be used in the design are defined, as are the required static design loads. Static tests to demonstrate the adequacy of the system in all loading directions are presented. Finally, dynamic test requirements, to demonstrate that the seat systems and restraint systems will provide the degree of protection desired, are also defined. Successful completion of all static tests and dynamic tests are required to demonstrate acceptability of a design.

The directions of applied loads are referred to in terms of forward or aftward, lateral or vertical, and upward or downward. These terms refer to seat loading in directions consistent with the aircraft coordinate system. Thus, a forward load on a forward-facing seat is in the positive x-direction with respect to both the seat and the aircraft. If the seat is a side-facing seat, the forward load would be applied to the seat in the plus-or-minus y-direction, depending on whether the seat faces right or left, respectively, in the aircraft. For an aft-facing seat, the forward load would be applied in the negative (-x)-direction toward the back of the seat.

2. OCCUPANT WEIGHTS FOR SEAT DESIGN AND TESTING

For design of single-occupancy seats, an occupant weight of 220 lb should be used. For multiple-occupancy seats, the seat should be considered fully occupied with a weight of 170 lb for each occupant.

The effective weight of a seated occupant in the vertical direction is approximately 80 percent of the occupant's total body weight because the lower extremities are partially supported by the floor. For downward loading of energy-absorbing seats the effective weight of the 50th-percentile occupant, 136 lb, should

be used in determining the limit load for the energy-absorbing system and for static testing. This 136-lb effective weight should be used in the downward direction for all energy-absorbing seats, whether single- or multiple-occupancy, and all such seats should be fully occupied.

3. AIRCRAFT SIZE CATEGORIES

In defining seat strength requirements it will be noted that the loads depend on aircraft size, as defined by passenger capacity. A certain degree of energy-absorbing capability below the floor has been assumed for each category, and, should a given aircraft possess less than the minimum assumed underfloor structure, the aircraft will be treated in the next smaller size category.

4. STRENGTH REQUIREMENTS

Required load factors for seat design are presented in Table 1. The static loads that the seat must withstand are obtained by multiplying the load factors by the sum of the seat weight and the total occupant weight, as defined in Section 2.

4.1 DOWNWARD LOADS - SMALL AIRCRAFT

Human tolerance to vertical impact limits the acceptable forces in the vertical direction for all aircraft seats. Therefore, for the small aircraft (less than 50 passengers or less than 36 in. of underfloor structure), energy absorption in the vertical (downward) direction must be provided. The seat should be designed for a minimum of 8 in. of stroke. The seat should stroke at a load of 12 ± 2 times the combined weight of the seat and effective weight of occupants at 136 lb per person.

BEST DOCUMENT AVAILABLE

TABLE 1. SEAT DESIGN AND STATIC TEST REQUIREMENTS

Fuselage Size / Loading Direction	Required Load Factor (G)		
	A. Small (Less than 50 passengers	B. Medium (50-249 passengers)[a]	C. Large (250 or more passengers)[b]
Forward	21	18	15
Lateral	12	10	8
Downward	12 ± 2[c]	10	8
Upward	8	6	4
Aftward	12	10	8

(a) Any aircraft possessing less than a 36-in. depth of fuselage structure below the floor must meet requirements of Category A (small).
(b) Any aircraft possessing less than a 60-in. depth but at least 36 in. of fuselage structure below the floor must meet requirements of Category B (medium).
(c) Energy-absorbing stroke is required, as explained in Section 4.1. Occupant weight for downward loading of a Category A seat should be the effective weight of 136 lb.

4.2 ATTACHMENT OF SEATS TO AIRCRAFT

Attachments to aircraft structure on floor or bulkheads must be capable of retaining the seat under its design loads, considering the effects of warping as discussed in Section 5.

Load-limiting between the seat and floor provides a potential alternative to increased floor strength in retrofit applications. However, it must be demonstrated by dynamic testing that injury potential will not be aggravated by the energy-absorbing seat displacement resulting from the use of load-limiting. For example, a fully occupied seat located behind an empty seat would be expected tc stroke toward the empty seat under forward loading. The reduction in space between the seats should be demonstrated to be nonhazardous.

BEST DOCUMENT AVAILABLE

5. STRUCTURAL TEST REQUIREMENTS

Both static and dynamic tests are recommended. Dynamic tests of aircraft seats have shown that individual components capable of maintaining the design loads often fail when tested in combination with other components. This could be a result of inaccurate analyses. However, it is recommended that all seat systems be tested as complete units. This is not to imply that component tests are not useful. Component tests can be extremely useful and should be used wherever possible to verify required strengths. This practice is particularly valid where finite-element analyses have been used to accurately predict distribution of loads in redundant structures.

Upon certification of prototype systems tested under both static and dynamic conditions, no further tests should be required. Major structural design changes in the basic seat system will require static retesting of the new system to ensure that no loss in strength has been caused by the design changes. If the changes could affect the energy-absorbing, or stroke, performance of the seat (Category A), additional dynamic tests should also be conducted. Major structural design changes are those changes involving principal load-carrying members such as floor, bulkhead, or ceiling tiedown fittings, structural links or assemblies, seat legs, or energy-absorbing systems. Minor changes, such as in ancillary fittings, can be accepted without a structural test. In summary, changes that increase loading, decrease strength, produce significant changes in load distribution, or affect the stroking mechanism will require retesting.

All testing is to be conducted with the seat cushions in place and, for pilot seats with adjustments, the seats should be in the full-up and full-aft positions unless another position is shown to be more critical.

BEST DOCUMENT AVAILABLE

5.1 STATIC TEST REQUIREMENTS

5.1.1 General

The purpose of the static tests is to demonstrate that the seat has the strengths and other properties required to provide the desired performance in all the principal loading directions. Static testing enables basic properties to be ascertained for known loads applied at a slow enough rate so that seat response can be observed. Successful completion of the static tests does not guarantee passing the dynamic tests, but it improves the chances. Weaknesses can be identified and corrected prior to conduct of the ultimate dynamic tests. Also, due to the loading rate sensitivity of materials, load distributions may be different in dynamic tests from those in static tests. Certain structures, statically soft, may react as stiffer members under dynamic loading, and thus, pick up more of the load than when the system was loaded statically.

Table 1 presents the static test requirements for complete seat units. The tests required include a series of unidirectional tests to determine basic seat strengths along the major axes. The loads should be applied separately, and seats must demonstrate no loss in structural integrity during these tests and should demonstrate acceptable energy-absorbing capacity (Downward - Category A). All static tests should be conducted under simultaneous conditions of floor buckling and warping as illustrated in Figure 1 or bulkhead warping as illustrated in Figure 2. The warping conditions must be introduced in the static test phase to evaluate completely the performance of the seat under the most severe requirements selected for design.

BEST DOCUMENT AVAILABLE

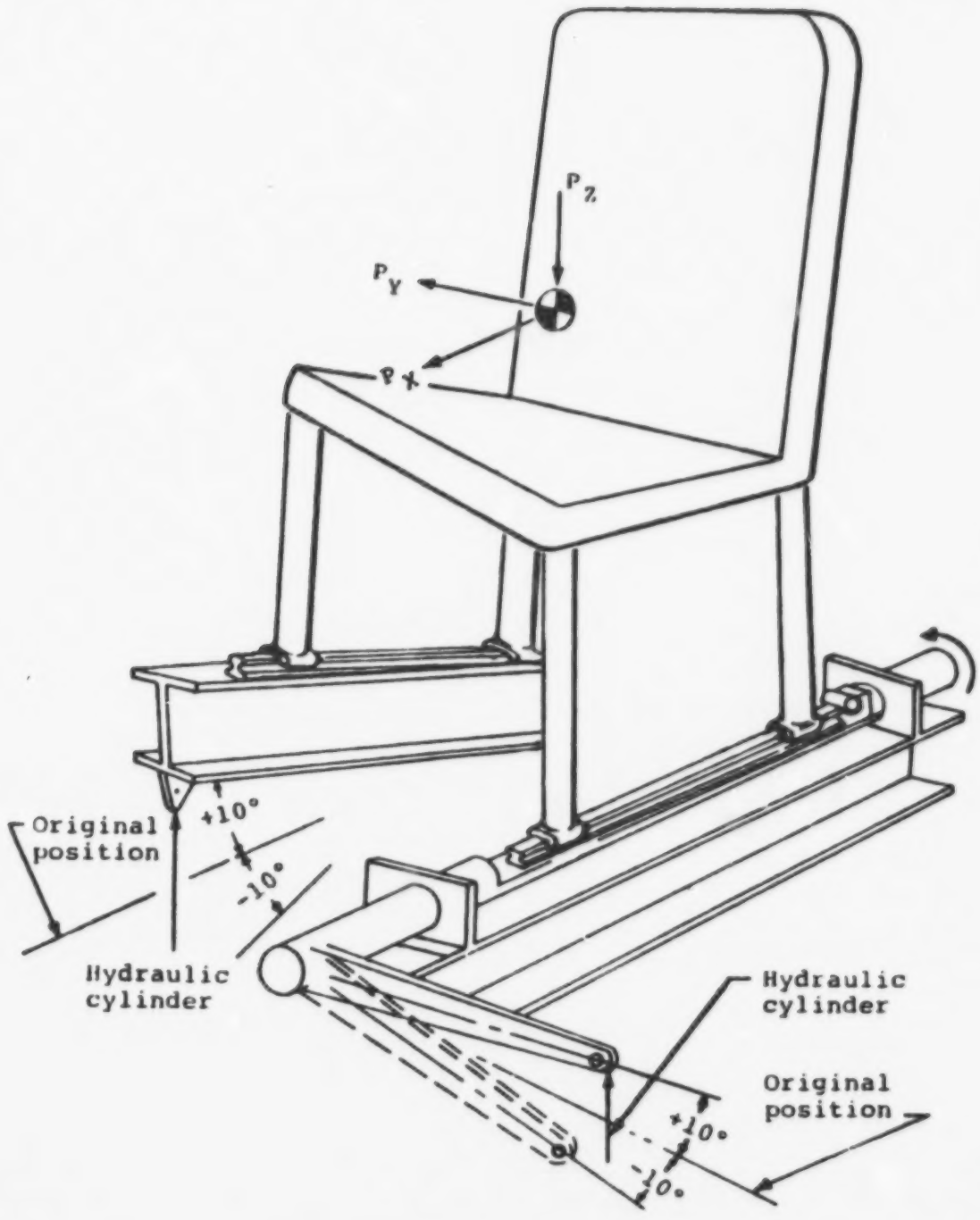


Figure 1. Suggested method of applying floor warp and twist during static loading of seats.

BEST DOCUMENT AVAILABLE

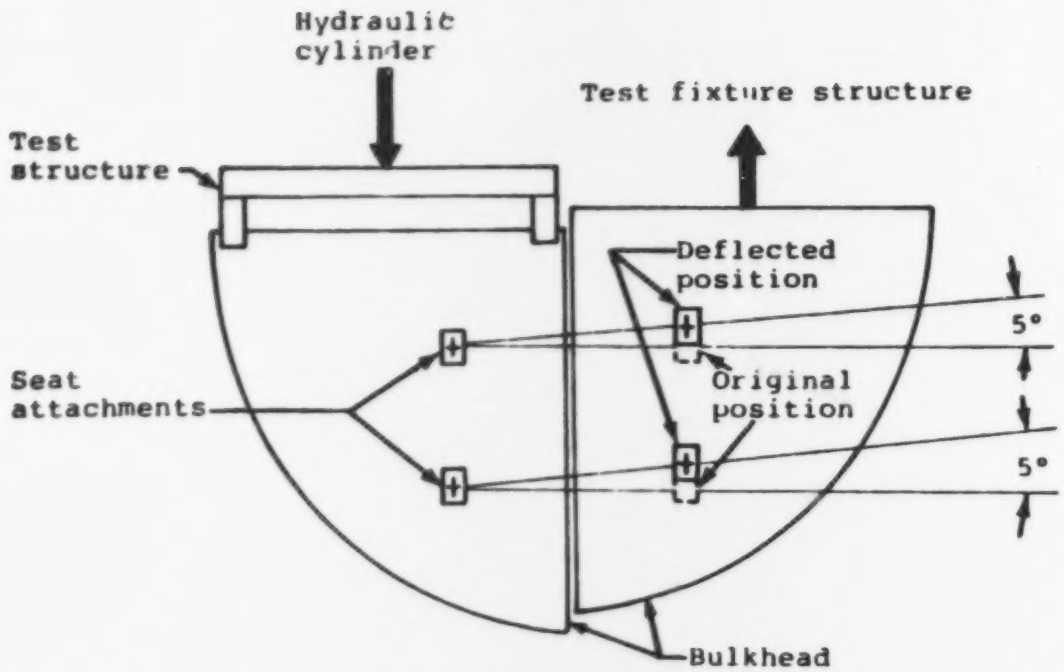


Figure 2. Suggested method of applying bulkhead warping for static testing of seats.

BEST DOCUMENT AVAILABLE

5.1.2 Load Application Method

The static test loads are to be applied at the expected center-of-gravity location of the occupant or occupants of each seat. The loads should be applied through a body block (see Section 5.1.3) restrained in the seat with the restraint system. Figure 3 shows the location of the center of gravity that should be used as the initial static load application point for the seat occupant.

The test load calculated by multiplying the weight of the occupant plus the weight of the seat by the required load factor should be applied continuously, or in not more than 2-G increments while the load-deformation performance of the seat is recorded. Maximum loads need not be held for more than 1 sec. The maximum load reached, regardless of duration, is to be used to assess compliance.

5.1.3 Static Load Body Block

The static test loads must be applied through a body block contoured to approximate a 95th-percentile occupant seated in a normal attitude. The body block must contain shoulders, neck, and upper legs. The upper legs should be contoured to simulate the flattened and spread configuration of seated thighs and to allow the proper location of the buckle. Critical pelvis dimensions are shown in Figure 3. The leg stubs should be configured to permit proper seat pan loading as the body block rotates forward under longitudinal loading; i.e., the leg stubs should be only long enough to provide a surface to react the lap belt load. The side view of the buttocks should include an up-curved surface forward of the ischial tuberosities to allow the forward rotation of the body block while maintaining the primary contact between the ischial tuberosities and the seat pan through the cushions.

BEST DOCUMENT AVAILABLE

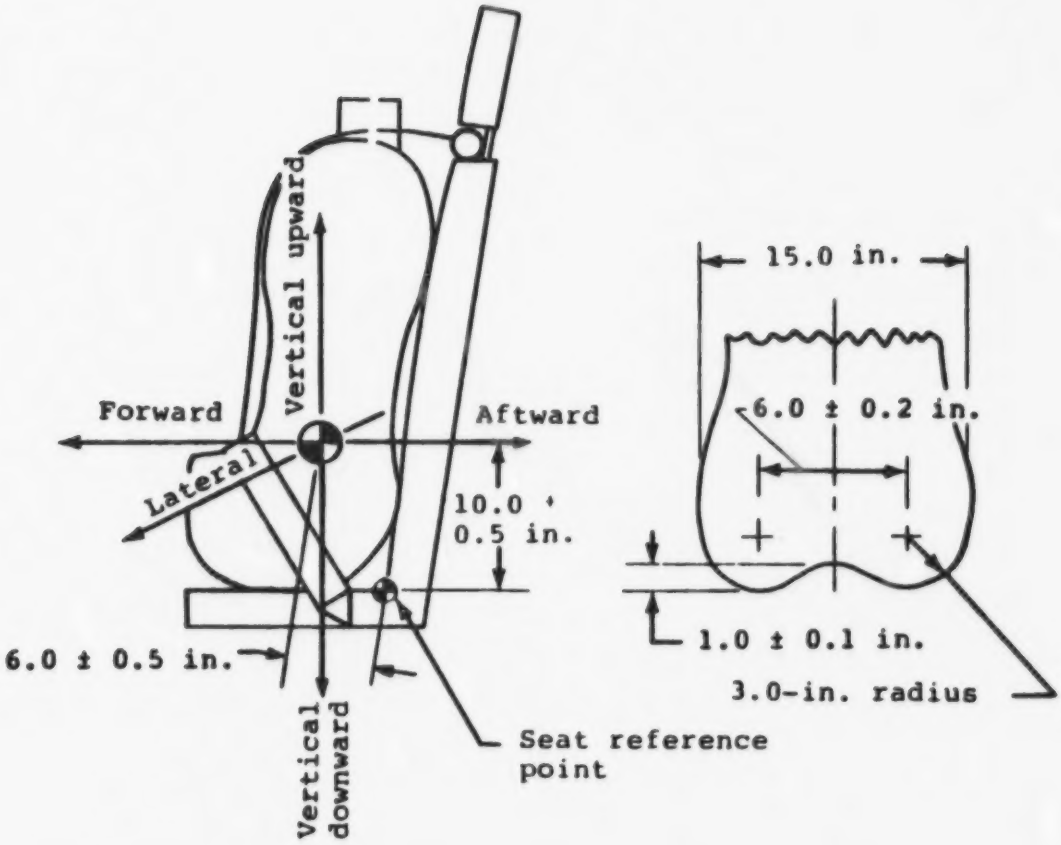


Figure 3. Static load application point and critical body block pelvis geometry.

BEST DOCUMENT AVAILABLE

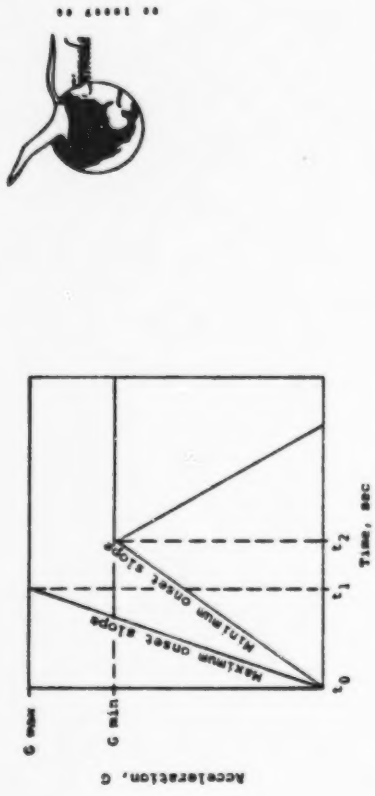
BEST DOCUMENT AVAILABLE

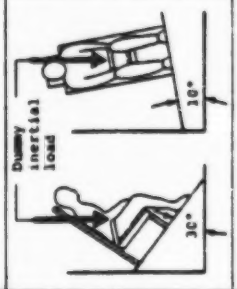
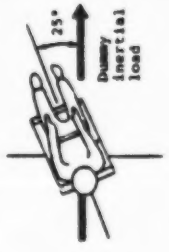
5.2 DYNAMIC TEST REQUIREMENTS

All seats should be dynamically tested to the two conditions specified in Figure 4. Test 1 is required to ensure that the vertical load-limiting provisions will perform satisfactorily under simultaneous forward and lateral loading conditions. Test 2 is required to ensure that the seat can resist the loads produced by the design pulse when applied simultaneously in the forward and lateral directions. A 50th-percentile anthropomorphic dummy complying with the Code of Federal Regulations, Title 49, Part 572 specification for dummies should be used to simulate the seat-system occupant for Test 1. A 95th-percentile anthropomorphic dummy simulating as closely as possible the features of the 50th-percentile dummy described above should be used to simulate the seat occupant for Test 2.

Dynamic testing of multiple-occupancy seats should be performed with the maximum number of occupants specified for the test seat. Additional tests should be run if it is determined that the most adverse loading condition occurs in other than full-occupancy situations. For both tests of Figure 4, adjustable (pilot) seats should be adjusted to the full-aft and up position of the adjustment range. Plastic deformation of the seat is permissible; however, structural integrity must be maintained in all tests. For Test 1, the seat should limit the acceleration as measured in the pelvis of the dummy to values which ensure that the occupant will not experience vertical, $+G_z$, accelerations in excess of human tolerance as defined in Figure 5. The roll direction (10 degrees right or left) for Test 1 should be the more critical loading for the specific seat design.

If load-limiting is used to meet the strength requirements in retrofit applications, the dynamic tests illustrated in Figure 6 should be substituted for the forward, lateral, and downward loading static tests. The downward loading dynamic test utilizes a 50th-percentile dummy; the others, a 95th-percentile device.



Test	Configuration	Parameter	A. Small (Less than 50 Passengers)	B. Medium[a] (50-249 Passengers)	C. Large[b] (250 or more Passengers)
1		t_1	0.109	0.120	0.155
		t_2 sec	0.147	0.160	0.175
		G min	19	17	14
		G max	22[c]	20	16
		Δv min, ft/sec	50	50	50
2		t_1	0.109	0.120	0.155
		t_2 sec	0.147	0.160	0.175
		G min	19	17	14
		G max	22	20	16
		Δv min, ft/sec	50	50	50

(a) Any aircraft possessing less than a 36-in. depth of fuselage structure below the floor must meet requirements of Category A (small).
(b) Any aircraft possessing less than a 60-in. depth but at least 36 in. of fuselage structure below the floor must meet requirements of Category B (medium).
(c) Energy-absorbing stroke is required, as explained in Section 4.1. Occupant weight for downward loading of Category A seat should be 136 lb.

Figure 4. Dynamic test requirements for qualification and for research/development testing.

BEST DOCUMENT AVAILABLE

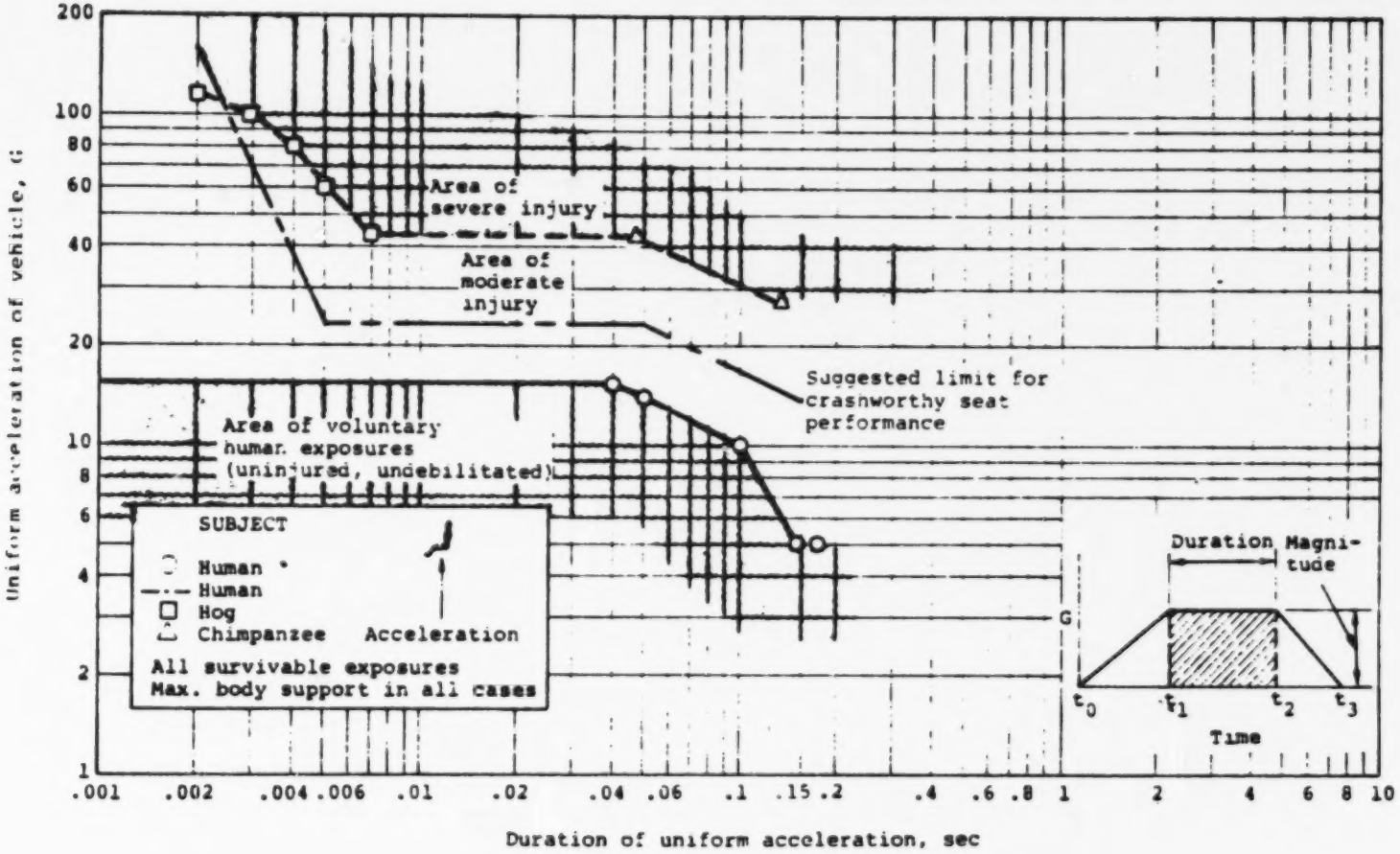
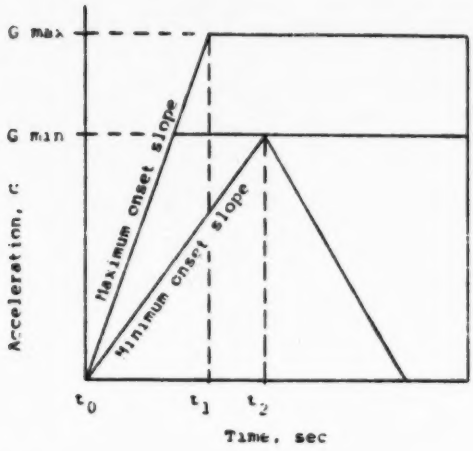
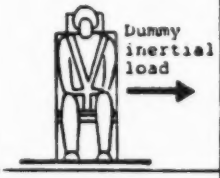
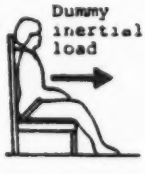


Figure 5. Duration and magnitude of loadward acceleration endured by various subjects.

BEST DOCUMENT AVAILABLE

EST_DOCUMENT_AVAILABLE



Test	Configuration	Parameter	A. Small (Less than 50 Passengers)	B. Medium[a] (50-249 Passengers)	C. Large[b] (250 or more Passengers)
1		t_1 sec	0.092	0.157	0.196
		t_2 sec	0.101	0.168	0.201
		G min	17	10	8
		G max	20[c]	12	10
		Δv min, ft/sec	36	36	36
2		t_1 sec	0.091	0.109	0.136
		t_2 sec	0.100	0.116	0.140
		G min	12	10	8
		G max	14	12	10
		Δv min, ft/sec	25	25	25
3		t_1 sec	0.109	0.128	0.155
		t_2 sec	0.122	0.140	0.175
		G min	20	17	14
		G max	23	20	16
		Δv min, ft/sec	50	50	50

(a) Any aircraft possessing less than a 36-in. depth of fuselage structure below the floor must meet requirements of Category A (small).
(b) Any aircraft possessing less than a 60-in. depth but at least 36 in. of fuselage structure below the floor must meet requirements of Category B (medium).
(c) Energy-absorbing stroke is required, as explained in Section 4.1. Occupant weight for downward loading of Category A seat should be 136 lb.

Figure 6. Requirements of additional dynamic tests if substituted for static tests.

The velocity change indicated in Figures 4 and 6 is based on the results of a crash test of a DC-7 transport into an 8-degree slope at an impact speed of 160 mph. The velocity change measured in this impact was 48 ft/sec (approximately 50 ft/sec), as presented in TR 67-16. The fuselage remained intact during this impact with the exception that a propeller blade penetrated the forward fuselage. Estimates in the U.S. Army's Crash Survival Design Guide, TR 71-22, showed a 95th-percentile survivable accident of fixed-wing transport aircraft to have a longitudinal velocity change of 64 ft/sec. However, other observations in survivable crashes, since this report was first published in 1965, indicate that conditions may be too severe. Therefore, the required test velocity change, which controls energy content, has been reduced to approximately that actually measured for the DC-7 test.

BEST DOCUMENT AVAILABLE

APPENDIX TABLE 1

ACCIDENTS/INCIDENTS MEETING CRITERIA

Date Mo-Yr	Aircraft Make and Model	Total Persons Aboard	Injuries				Fire After Impact	Phase of Operation	Airport Proximity	Accident Type
			Fatal	Serious	Minor	None				
1-70	DC-9	41	0	0	0	41	No	Approach	On	Collision with Obstacle
5-70	DC-9	63	23	11	6	23	No	Landing	>5	Engine Failure or Malfunction
7-70	B-737	61	0	1	19	41	No	Takeoff	On	Engine Failure or Malfunction
9-70	DC-8	156	0	11	54	91	No	Landing	On	Hard Landing
11-70	B-747	163	0	7	16	140	No	Climb	>5	Turbulence
11-70	DC-8	229	47	49	0	133	Yes	Takeoff	On	Collision with Obstacle
12-70	B-727	55	2	11	39	3	Yes	Landing	On	Hard Landing
1-71	B-707	21	0	0	0	21	No	Descent	>5	Collision with Aircraft
2-71	DC-9	11	0	0	1	10	No	Approach	1–5	Collision with Obstacle
5-71	B-747	42	0	0	0	42	No	Takeoff	1–5	Fire or Explosion in Flight
6-71	CV-580	31	28	3	0	0	Yes	Approach	On	Collision with Obstacle
6-71	B-707	55	0	0	4	51	No	Cruise	>5	Evasive Maneuver
6-71	DC-9	8	0	0	0	8	No	Approach	1–5	Collision with Ground/Water
7-71	B-747	218	0	10	19	189	No	Takeoff	On	Collision with Obstacle
8-71	B-707	96	0	0	0	96	No	Approach	On	Collision with Aircraft
12-71	DC-9	27	0	0	0	27	No	Approach	On	Collision with Aircraft
1-72	B-747	330	0	5	37	288	No	Cruise	>5	Turbulence
3-72	FH-227B	46	16	32	0	0	No	Approach	1–5	Prop/Rotor Failure
4-72	B-747	160	0	2	12	146	No	Cruise	>5	Turbulence
4-72	B-727	94	0	0	2	92	No	Descent	>5	Evasive Maneuver
5-72	DC-9	10	0	3	0	7	Yes	Landing	On	Collision with Ground/Water
6-72	DC-10	67	0	0	11	56	No	Climb	>5	Airframe Failure
8-72	B-707	186	0	0	16	170	Yes	Takeoff	On	Collision with Obstacle
12-72	B-737	61	43	12	2	4	Yes	Approach	1–5	Stall/Mush
12-72	DC-9	45	10	9	5	21	Yes	Takeoff	On	Collision with Aircraft
12-72	CV-880	93	0	0	2	91	No	Taxi	On	Collision with Aircraft
12-72	L-1011	176	99	60	17	0	No	Approach	>5	Collision with Ground/Water
12-72	B-747	160	0	0	4	156	No	Landing	On	Engine Failure or Malfunction
4-73	B-727	37	0	0	0	37	No	Approach	1–5	Collision with Obstacle
6-73	DC-8	261	0	3	31	227	Yes	Takeoff	On	Airframe Failure
6-73	DC-8	128	0	8	0	120	Yes	Landing	On	Undershoot
7-73	FH-227B	44	36	6	0	0	Yes	Approach	1–5	Collision with Ground/Water
8-73	B-707	152	1	3	1	147	No	Descent	>5	Miscellaneous
10-73	B-737	96	0	0	5	91	Yes	Landing	On	Overshoot
11-73	DC-10	128	1	0	24	103	No	Cruise	>5	Engine Failure or Malfunction
11-73	DC-9	79	0	4	38	37	Yes	Approach	On	Undershoot
11-73	DC-9	26	0	16	10	0	No	Landing	On	Overshoot
12-73	DC-10	167	0	3	13	151	Yes	Landing	On	Undershoot
1-74	B-707	65	0	2	6	57	Yes	Landing	On	Hard Landing
1-74	B-707	101	96	5	0	0	Yes	Landing	On	Undershoot
5-74	B-707	111	0	3	12	96	No	Cruise	>5	Turbulence
7-74	DC-10	172	0	0	0	172	No	Climb	>5	Airframe Failure
9-74	DC-9	82	71	10	0	0	Yes	Approach	1–5	Collision with Ground/Water
3-75	B-737	99	0	1	3	95	No	Landing	On	Overshoot
6-75	B-727	124	112	12	0	0	Yes	Approach	On	Undershoot
8-75	B-727	134	0	15	0	119	No	Takeoff	On	Collision with Ground/Water
8-75	DC-10	231	0	3	18	210	Yes	Takeoff	On	Airframe Failure
8-75	F-27B	32	10	20	2	0	Yes	Approach	On	Collision with Ground/Water
11-75	B-727	139	0	1	7	131	No	Landing	On	Undershoot
11-75	DC-10	139	0	2	30	107	Yes	Takeoff	On	Engine Failure or Malfunction
11-75	DC-10	191	0	3	21	167	No	Cruise	>5	Evasive Maneuver
12-75	B-747	121	0	2	9	110	No	Taxi	On	Ground-Water Loop-Swerve
4-76	DC-9	176	0	0	0	176	No	Approach	On	Evasive Maneuver
4-76	B-727	50	1	11	23	15	Yes	Landing	On	Overshoot
4-76	B-727	86	37	19	29	3	Yes	Landing	On	Overshoot
6-76	L-188	45	45	0	0	0	Yes	Takeoff	On	Engine Failure or Malfunction
6-76	DC-9	106	0	86	0	20	No	Approach	On	Collision with Ground/Water
11-76	DC-9	96	0	2	15	69	Yes	Takeoff	On	Collision with Obstacle
4-77	DC-9	85	62	22	1	0	Yes	Cruise	>5	Engine Failure or Malfunction
6-77	B-727	91	0	0	0	91	No	Takeoff	On	Collision with Obstacle
3-78	DC-10	200	2	31	54	113	Yes	Takeoff	On	Airframe Failure
5-78	B-727	58	3	11	21	23	No	Approach	1-5	Collision with Ground/Water
6-78	DC-9	–	0	0	0	–	No	Takeoff	On	Evasive Maneuver
7-78	BAC 1-11	77	0	1	9	67	No	Landing	On	Overshoot
7-78	CV-580	43	0	3	30	10	No	Takeoff	1–5	Engine Failure or Malfunction
10-78	B-727	110	0	4	3	103	No	Static	On	Miscellaneous
11-78	DC-9	83	0	0	0	83	No	Takeoff	On	Stall/Mush
12-78	DC-8	189	10	23	50	106	No	Approach	>5	Engine Failure or Malfunction
2-79	NORD 262	25	2	8	15	0	No	Takeoff	On	Collision with Ground/Water
2-79	B-727	115	0	0	0	115	No	Taxi	On	Collision with Aircraft
2-79	B-747	6	0	0	0	6	No	Landing	On	Collision with Aircraft
3-79	NORD 262	7	3	0	0	4	No	Takeoff	1–5	Engine Failure or Malfunction
4-79	B-727	89	0	0	8	81	No	Cruise	>5	Uncontrolled Altitude Deviation
8-79	B-727	77	0	0	0	77	No	Approach	1–5	Turbulence
9-79	DC-9	45	0	0	1	44	No	Climb	>5	Airframe Failure
11-79	DC-10	311	0	0	0	311	No	Climb	>5	Stall/Mush
3-80	DC-9	50	0	1	22	27	No	Landing	>5	Overshoot
3-80	DC-9	52	0	0	7	45	No	Cruise	>5	Airframe Failure
2-81	B-737	111	0	3	31	77	Yes	Landing	On	Gear Retracted

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

APPENDIX TABLE 2

ACCIDENTS/INCIDENTS WITH FAILURES

Date Mo-Yr	Aircraft Make and Model	Total Persons Aboard	Crew Injuries				Passenger Injuries				Fire After Impact	Phase of Operation	Aircraft Proximity	Terrain Conditions	Obstacles Collided With	Failures				
			Fatal	Serious	Minor	None	Fatal	Serious	Minor	None						Seats/ Restraints	Seat Track/ Floor	Overhead Furnishings	Galley Equipment	Emergency Equipment
5-70	DC-8	83	1	0	1	4	22	11	5	10	No	Landing	>5	Water Submerged		✓	✓	✓	✓	
7-70	B-737	81	0	0	1	5	0	1	15	30	No	Takeoff	On	Runway, Hard Packed Earth, Brush & Swamp	Runway Lights, Chainlink Fence, 2 Wheels of Forks & Rubble	✓		✓	✓	
8-70	DC-8	150	0	0	1	9	0	11	53	82	No	Landing	On	Runway, Sandy Ground		✓	✓		✓	✓
11-70	B-747	163	0	1	1	13	0	0	15	127	No	Climb	>5	N/A		✓		✓		
11-70	DC-8	229	1	0	0	3	46	42	0	136	Yes	Takeoff	On	Runway, Frozen Ground	ILS Antenna, Wooden Fence, 12 ft. Ditch	✓		✓	✓	✓
12-70	B-727	65	0	2	1	0	2	0	34	3	Yes	Landing	On	Runway, Turf	Chainlink Fence, Concrete Walkway, Roadway, 25 ft. Hill	✓		✓		
7-71	B-747	218	0	0	0	10	0	10	19	178	No	Takeoff	On	Runway	Approach Lights and Support Structure		✓	✓		
1-72	B-747	330	0	1	3	0	0	4	34	278	No	Cruise	>5	N/A		✓		✓		
3-72	FH-227	48	2	1	0	0	14	31	0	0	No	Approach	1-5	City Area	Fence, House	✓	✓	✓	✓	
5-72	DC-9	10	0	2	0	2	0	1	0	5	Yes	Landing	On	Runway		✓		✓	✓	
6-72	DC-10	67	0	0	2	0	0	0	0	47	No	Climb	>5	N/A			✓	✓	✓	
12-72	B-737	81	3	1	0	2	48	11	2	2	Yes	Approach	1-5	City Area	Runway40, Garage23, Trees, Poles	✓		✓	✓	
12-72	DC-9	45	0	0	1	3	18	0	4	18	Yes	Takeoff	On	Runway	Aircraft	✓				
12-72	CV-880	83	0	0	0	7	0	0	2	84	No	Taxi	On	Runway	Aircraft			✓		✓
12-72	L-1011	176	5	10	0	0	94	58	17	0	No	Approach	>5	Swamp		✓	✓			
6-73	DC-8	129	0	2	0	7	0	0	0	113	Yes	Landing	On	Runway		✓		✓		✓
7-73	FH-227	44	1	2	0	0	37	4	0	0	Yes	Approach	1-5	City Area	Trees, Power Lines, Houses	✓	✓		✓	
8-73	B-707	152	0	1	1	0	1	2	0	138	No	Descent	>5	N/A		✓			✓	
10-73	B-737	66	0	0	1	3	0	0	4	58	Yes	Landing	On	Runway, Hard Packed Earth		✓		✓	✓	
11-73	DC-9	79	0	2	2	1	0	2	26	36	Yes	Approach	On	Turf	Approach Lights, Dike	✓	✓	✓	✓	
11-73	DC-9	28	0	3	2	0	0	13	0	0	No	Landing	On	Runway, Hard Packed Earth	30 ft. Embankment	✓	✓	✓		
12-73	DC-10	167	0	1	0	13	0	2	13	138	Yes	Landing	On	Runway, Hard Packed Earth	Approach Lights, Embankment	✓	✓	✓	✓	
9-74	DC-9	82	2	1	1	0	68	0	0	0	Yes	Approach	1-5	Woods	Trees	✓			✓	
3-75	B-737	80	0	0	0	0	0	1	3	66	No	Landing	On	Runway, Hard Packed Earth	Approach Lights, Ditch, Fence			✓	✓	
6-75	B-727	124	0	2	0	0	100	10	0	0	Yes	Approach	On	Marsh	Approach Lights, Boulders, Embankment	✓	✓			
8-75	B-727	134	0	5	0	2	0	10	0	117	No	Takeoff	On	Hard Packed Earth		✓	✓	✓	✓	
8-75	F-27	32	3	1	0	0	7	19	2	0	Yes	Approach	On	Mountainous	Rocks, Boulders	✓		✓	✓	
11-75	B-727	130	0	0	0	0	0	1	7	122	No	Landing	On	Runway-Hard Packed Earth	Approach Lights	✓		✓	✓	
11-75	DC-10	139	0	2	3	0	0	0	27	107	Yes	Takeoff	On	Runway				✓		
11-75	DC-10	191	0	0	10	3	0	3	11	164	No	Cruise	>5	N/A		✓		✓		
12-75	B-747	121	0	1	2	17	0	1	7	93	No	Taxi	On	Runway-Ice Covered	30 ft. Embankment, Trees	✓	✓	✓	✓	✓
4-76	B-727	58	0	5	2	0	1	0	21	29	Yes	Landing	On	Runway, Gravel, Hard Packed Earth	Antennas, Boulders, Tree Stumps, Ditch	✓	✓		✓	
4-76	B-727	88	2	2	3	0	35	17	26	3	Yes	Landing	On	Runway	Antennas, Embankment, Trees, Shack Building, Fence, Autos	✓		✓	✓	
6-76	L-188	46	12	0	0	0	33	0	0	0	Yes	Takeoff	On	Hard Packed Earth	Embankment, Fence, Auto, Trees	✓				
6-76	DC-9	105	0	4	0	0	0	82	0	20	No	Approach	On	Turf, Runway		✓	✓	✓	✓	
11-76	DC-9	86	0	0	3	2	0	2	12	67	Yes	Takeoff	On	Runway	Approach Lights, Two Ditches, Glide Slope Gooseneck				✓	
4-77	DC-9	85	2	1	1	0	60	21	0	0	Yes	Cruise	>5	Forrest, Highway	Trees, Autos, Building, Poles	✓	✓	✓	✓	
3-78	DC-10	290	0	3	11	0	2	28	43	113	Yes	Takeoff	On	Runway				✓		
5-78	B-727	56	0	2	4	0	3	0	17	33	No	Approach	1-5	Water (Unintentional)		✓	✓	✓		
7-78	BAC 1-11	77	0	0	1	3	0	1	0	64	No	Landing	On	Hard Packed Earth	Ditch	✓		✓	✓	
7-78	CV-580	43	0	1	2	0	0	2	28	10	No	Takeoff	1-5	Ploughed Ground	Corn Stalks	✓		✓		
12-78	DC-8	180	2	2	3	1	0	21	47	105	No	Approach	>5	City Area	Trees, Houses, Poles	✓	✓	✓		
2-79	NORD 262	25	1	1	1	0	1	7	14	0	No	Takeoff	On	Runway		✓	✓	✓		
4-79	B-727	88	0	0	0	7	0	0	0	74	No	Cruise	>5	N/A				✓	✓	
3-80	DC-9	50	0	0	3	1	0	1	19	26	No	Landing	On	Runway, Turf	Ditch	✓	✓	✓	✓	
2-81	B-737	111	0	0	0	5	0	3	31	72	Yes	Landing	On	Runway, Turf		✓	✓		✓	

U.S. GOVERNMENT PRINTING OFFICE : 1981 0-361-829/85